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Use of a Vegetative Filter Zone to Control Fine-Grained Sediments from Surface Mines

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This project was initiated with the specific purpose of conducting a field test on vegetation as a viable sediment trapping medium. From the onset, the project was wholly designed for a field evaluation under typical mining conditions. The filter area was constructed directly below an abandoned surface mine bench, on typical soil types found in mined areas of Eastern Kentucky. The outslope located above the filter was the primary area from which sediment-laden drainage was to be diverted to the inlet monitoring station. Sediment-laden water samples were collected at the inlet flume for comparison with samples collected at the outlet flume to permit evaluation of the sediment removal capability of the vegetative filter.

Results of the monitoring efforts revealed that a dramatic reduction in sediment load was achieved by vegetative filtration for particle sizes larger than clay. Based on results of this study, it is concluded that vegetative filters are an effective control for reducing the quantity of sediment transported in surface streams and rivers from disturbed mined lands.

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USE OF A VEGETATIVE FILTER ZONE TO CONTROL FINE-GRAINED SEDIMENTS FROM SURFACE MINES

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in cooperation with
Kentucky Department for Natural Resources
and Environmental Protection

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollutional control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

Federal and state regulatory agencies are involved in the reclamation of mined lands and the elimination or reduction of sediment-laden drainage which pollutes rivers and streams. This report evaluates the effectiveness of using vegetative filters to trap fine-grained sediments through the results of a field demonstration. This report is intended to aid private industry and government agencies in the reclamation of mined lands. For further information, contact the Energy Pollution Control Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory

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ABSTRACT

The objective of this study was "to demonstrate the effectiveness of a vegetative filter zone in trapping fine-grained sediments from surface mining operations". The area selected for study was located in Whitley County, Kentucky, directly below an active surface mining operation. The outslope above the filter was the primary drainage area monitored during the study.

This project was initiated with the specific purpose of conducting a field test on vegetation as a viable sediment trapping medium. From the onset, the project was wholly designed for a field evaluation under typical mining conditions. The filter area was constructed directly below an abandoned surface mine bench, on typical soil types found in mined areas of Eastern Kentucky. The outslope located above the filter was the primary area, from which sediment-laden drainage was to be diverted to the inlet monitoring station. Sediment-laden water samples were collected at the inlet flume for comparison with samples collected at the outlet flume to permit evaluation of the sediment removal capability of the vegetative filter.

Results of the monitoring efforts revealed that a dramatic reduction in sediment load was achieved by vegetative filtration for particle sizes larger than clay. Based on results of this study, it is concluded that vegetative filters are an effective control for reducing the quantity of sediment transported into surface streams and rivers from disturbed mined lands.

This report was submitted in fulfillment of Cooperative Agreement CS-805632 by Hittman Associates, Inc., Natural Resource Consultants, and the University of Kentucky, all of Lexington, Kentucky. This report covers the period of June 31, 1979 to March 31, 1981.

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The Vegetative Filter Zone Demonstration Project was a cooperative effort between the U.S. Environmental Protection Agency (EPA) and the Kentucky Department for Natural Resources and Environmental Protection (KY. DNREP). The work was conducted under contract by Hittman Associates, Inc. (HAI), Natural Resource Consultants, (NRC) and the University of Kentucky Department of Agricultural Engineering.

During the course of this project, many individuals contributed to the study. Without the contributions of these individuals, the project's success would never have been realized.

Direct management of the project was provided by Steve C. Albrecht, (HAI), The project consultant was Dr. Billy J. Barfield, (NRC). The project manager for the KY. DNREP was Richard Rohlf. The EPA project officer was Edward Bates of the Industrial Environmental Research Laboratory (EPA), Cincinnati.

Other individuals who provided valuable contributions during the course of the project include: Dr. R. I. Barnhisel, Mike Ruetten, David Kerr, Bill Harris, Loyd Dunn, Jim Penman, and Julia Peace.

Savoy Coal's cooperation in providing the project study site is also gratefully acknowledged.

SECTION 1

INTRODUCTION

The coal regions of the United States are richly endowed with abundant mineral resources. The surface mining of these valuable resources results in a major disturbance of the land. This disturbance interrupts a natural balance between soils and geologic formations established over many years. When highly erodible surface material is broken up, a natural pollutant, sediment, is introduced into rivers and streams. Surface mining operations often serve to accelerate the amount of sediment introduced into the environment. The resulting sedimentation can adversely affect local and surrounding ecosystems.

Various structures such as ponds, rock dams, silt fences, as well as other devices can be used to control sediment on surface mining operations. This report addresses the usefulness of one particular type of sediment control structure, the vegetative filter zone.

The objective of this study was to demonstrate under actual field conditions the tecnnical, economic, and environmental feasibility of using a cultivated vegetative filter zone to assist in controlling fine-grained sediments originating from surface mining operations. Project evaluation criteria focused on the sediment trapping efficiency of the filter, the suitability of selected types of vegetation for use within the filter zone, the filter's usefulness in improving water quality, and its cost feasibility. In the past, vegetation has been used extensively as a method of controlling erosion and to reduce the amount of sediment generated on surface mining operations. Unfortunately, little information was available concerning design criteria for the use of vegetation in trapping sediment, thus it was very difficult to incorporate this trapping method into a complete mining plan. Through the course of this demonstration project, strong emphasis was placed on developing practical vegetative field applications which could effectively be used by surface mine operators to control sediment. Specific design criteria were utilized for constructing the vegetative filter. The use of such criteria was necessary to provide for adequate control of the demonstration monitoring program. Mine operators wishing to utilize vegetative filters, will not have to utilize such design criteria to the extent required in this project.

This report provides detailed background information concerning sediment control technology, legislation and funding, site selection criteria, and project objectives (Section 3). In addition, the study provides baseline information on site characteristics, mining, geology, soils, vegetative design, hydrologic design, and water monitoring system design (Section 4). Installation of the filter, including site alterations, vegetative establishment and performance, monitoring system installation, time and materials are discussed in detail (Section 5).

Discussions of lab analyses, storm events, and computer model applications are also provided (Sections 6-8). The appendices contain storm event data, design storm calculations and descriptions of all analytical procedures utilized during the project.

SECTION 2

SUMMARY AND CONCLUSIONS

A field demonstration project was conducted near the city of Corbin in Southeastern Kentucky to evaluate the effectiveness of a vegetative filter zone in trapping fine-grained sediments from surface mining operations. Activities conducted during the project were: construction of a filter below an area generating sediment-laden runoff from surface mining; evaluation of vegetation as a trapping medium and the adaptability of the vegetation to the prolonged stress conditions; water and sediment monitoring of inlet and outlet flows through the filter area; water sample analyses for total solids; and analysis of particle size distribution of the trapped sediment.

Conclusions drawn from this study are as follows:

1) By vegetative filtration, a range of from 70 - 99 percent of all fine-grained sediments can be removed. This percentage does not include clays held in suspension. This range was determined from all data recorded during storm events.

2) Vegetative filter areas can normally be constructed using equipment found on most surface mining operations.

3) Vegetation used in the filter are subjected to high stress conditions. Response to this stress was excellent despite acid inflow into the area. Based upon the results of this study, the vegetative trapping medium can adapt to severe environmental conditions with very little difficulty.

4) The Kentucky Grass Filter Model was found to be excellent in predicting trapping efficiencies, given parameters of the individual storm events.

5) The trapping efficiency in storms early in the monitoring period were very high (95-100 percent), but toward the end of the period, trapping efficiencies had decreased approximately 75 percent.

SECTION 3

BACKGROUND

OVERVIEW OF EROSION AND SEDIMENT CONTROL TECHNOLOGY

The Erosion Process

Soil erosion occurs as a result of the exposure of detachable soil particles to the erosive forces of falling raindrops and flowing water. Soil is least protected from these forces when the surface is bare of vegetation or mulches. These conditions are typically associated with active surface mining and construction activities. It is impossible to perform such earth moving activities without leaving the surface exposed to these erosive forces for a period of time. It is possible, however, to control excessive stream pollution by trapping a significant amount of sediment before it leaves the permitted area.

Soil erosion occurs in rill and interrill areas on exposed hillsides or slopes. Rills are small fingerlike channels that are formed by the localized concentration of runoff water. Erosion in interrill areas is primarily due to the impact force of raindrops on the soil surface, while rill erosion is primarily due to the shearing forces of runoff. Gully erosion occurs when large volumes of runoff are concentrated onto an unstabilized area. Areas where the potential for gully erosion is high include uncontrolled drainage ditch outlets, drainage culvert outlets, and tile outlets.

Soil erosion involves detachment, transport, and the ultimate redeposition of sediment. Soil is detached by raindrop impact and the shearing forces of runoff, and is then transported by flowing water. Runoff and resulting transport of sediment does not occur until the rainfall rate exceeds the infiltration rate. Once runoff starts, the quantity and size of material transported increases with the velocity of runoff.

The rate of erosion from an exposed slope will be controlled by gravity and the soil available for transport, or the transport capacity of the flow, whichever is smaller (Figure 1). On long steep slopes, the transport capacity of

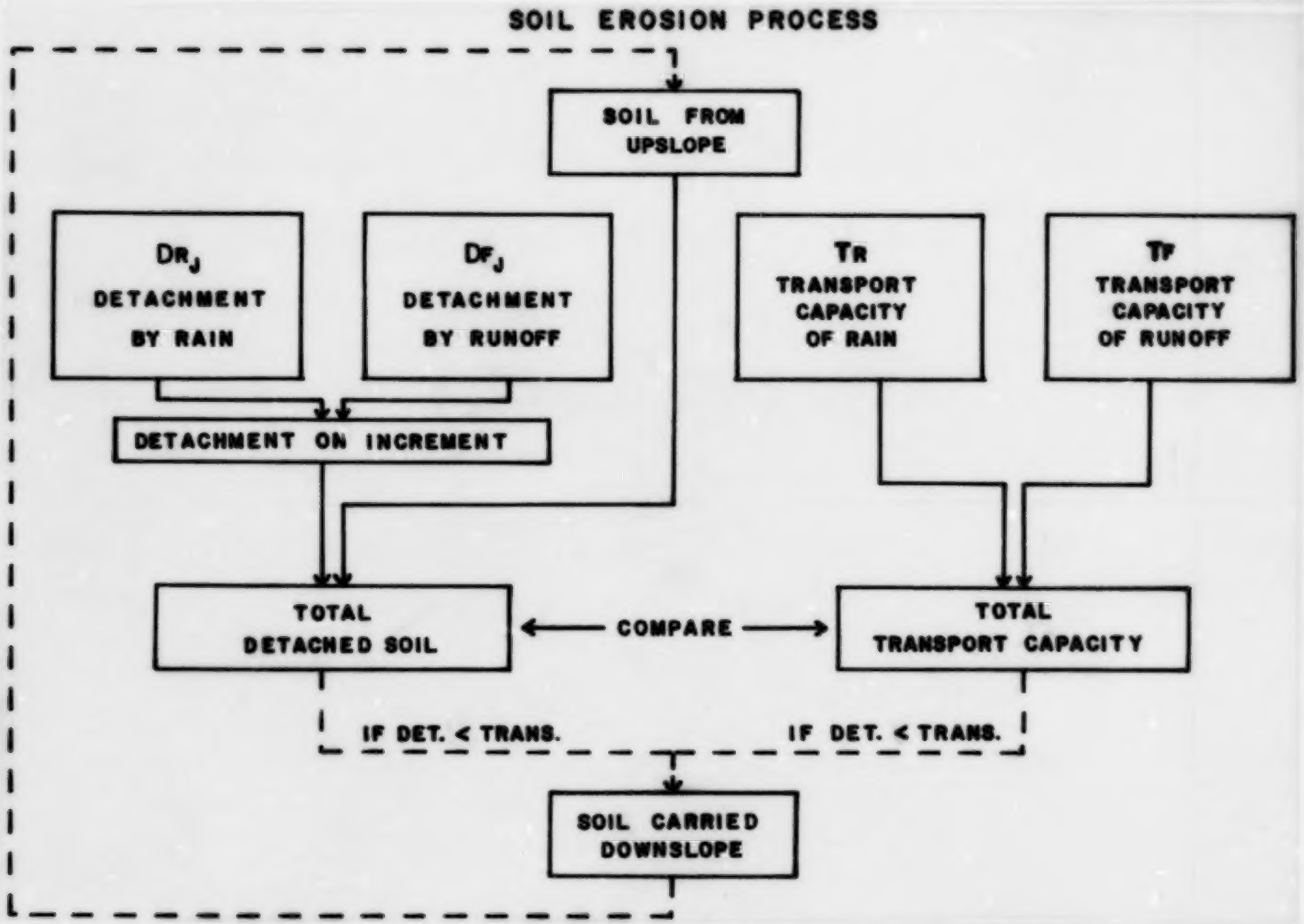

SOIL EROSION PROCESS
SOIL FROM UPSLOPE
Dr_J DETACHMENT BY RAIN
Df_J DETACHMENT BY RUNOFF
TR TRANSPORT CAPACITY OF RAIN
TF TRANSPORT CAPACITY OF RUNOFF
DETACHMENT ON INCREMENT
TOTAL DETACHED SOIL
COMPARE
TOTAL TRANSPORT CAPACITY
IF DET. < TRANS.
IF DET. < TRANS.
SOIL CARRIED DOWNSLOPE

Figure 1. Schematic of the process of soil erosion by water. (Meyer, 1974)

the flow will typically be less than the sediment available for transport, resulting in deposition. The use of properly designed vegetative filters optimizes deposition in a natural filtration process.

Erosion and Sediment Control Technology

Sediment control can be influenced by either limiting the detachment rate or transport capacity (Figure 1). Detachment due to raindrop splash can be primarily reduced by absorbing the energy of raindrops on some type of cover, which may be permanent vegetation, temporary mulches, or chemical binders used to stabilize soil and to make it more resistant to erosion. The rate of detachment due to runoff can also be reduced by making the soil more resistant to erosion, as with chemical stabilizers, the addition of organic matter to the soil, or by reducing the runoff velocity. Any practice that roughens the surface, such as mulches or contour tillage, decreases the runoff velocity and hence the shearing forces of runoff. The sediment transport capacity of runoff also monotonically increases with velocity, and can be reduced by the application of practices used to reduce erosion by runoff.

Erosion and sediment control techniques can be grouped into on-site and off-site practices. On-site practices such as mulching, establishment of a vegetal cover, and runoff control are used to reduce both detachment and transport capacity. These practices provide a "first line of defense" against sediment pollution, but can only be used practically after grading has been completed.

Offsite techniques such as the use of sediment detention reservoirs, sediment traps, check dams, and vegetative filters can help reduce the transport capacity of runoff. Sediment traps, check dams, and sediment detention reservoirs typically trap sediment a considerable distance from the point of detachment. Vegetative filters can be located at points downslope or downstream of a sediment source, but are most effective when located as close as possible to the point of detachment. In the demonstration project described in this report, a vegetative filter was located near the base of an abandoned surface mine spoil outslope in order to monitor its effectiveness in trapping sediment near the point of soil detachment.

Description of Previous Work

Flow Retardation by Vegetation --

Early research by Ree (1949) considered the hydraulic characteristics of vegetation used as vegetative waterways.

He noted that resistance of a vegetation to flowing water is its most important hydraulic characteristic. Determinations of the retardance coefficient, using Manning's equation, were made for different vegetations under a variety of conditions. Manning's equation is given by

$$V_m = \frac{1}{n} R^{2/3} S_c^{1/2}$$

where V_m is the mean velocity, R is the hydraulic radius, S_c is the channel slope, and n is the retardance coefficient which is usually referred to as Manning's roughness. The values of Manning's n ranged widely, even for the same vegetation in the same channel. A gradual increase in n was noted by Ree as the discharge increased. As discharge further increased, a depth was reached where the grass bent over and became submerged. The n values then rapidly decreased with flow depth until the grass was completely bent over, at which time the Manning's n begin to approach a constant value. Permissible velocities for a vegetation to protect against erosion were found to depend on the type and quality of vegetation, the soil texture in the channel bed, and channel slope. Ree cautioned that complete sod vegetations allow the highest permissible velocities, and bunch-type permit the lowest. A total sod cover gives complete channel protection, while the bunch-type grasses leave unprotected bare areas between the clumps.

Fenzl and Davis (1964) discussed the difficulties in adequately characterizing the hydraulic resistance for open-channel flow through vegetation in irrigation borders. Two essential design criteria, which must be adhered to in order to satisfactorily design vegetative channels, are: 1), the channel must be able to carry the flow, and 2), the channel bed must remain stable. Dimensional analysis of relevant variables was used in the development of a proposed procedure. An analytical model defining flow resistance for vegetated channels was presented by Thompson and Roberson (1976). This relationship considered the total flow resistance to be composed of flow resistance caused by the vegetative elements in the flow and by the roughness of the channel surface unoccupied by vegetation. The resistances were separated by source component, and basic laws of fluid dynamics were used to describe the flow. Kouwen et al. (1969) presented a quasitheoretical analysis for flow retardance in vegetative channels by anticipating that most of the parameters found to affect flow resistance in channels with rigid roughness will also be present with flexible roughness, such as represented by grass and other vegetation. This approach based the flow equation for vegetated channels on the vegetative characteristics, including vegetative-blocked cross-sectional area and roughness coefficient.

In response to Kouwen et al. (1969), Gourlay (1970) observed that a complete solution for resistance in a vegetated channel should strive toward expressing the flow velocity as a function of the independent variables of flow rate, slope, and physical characteristics of the grass. Typical grass physical characteristics would be grass height, the number of stems per unit area, a factor accounting for grass resilience, and the shape of the stems or blades. Since several flow regimes are possible, a prediction of which flow regime occurs for a given condition is also essential.

Li and Shen (1973) believed that vegetation serves as an effective method of reducing sediment yield by protecting the soil from rainfall impact energy, retarding the flow, reducing soil resistance and aiding infiltration. After testing a number of different patterns of vegetation, Li and Shen concluded that vegetation has a significant effect on retardation of flow rates and sediment yields, and that vegetation planted in staggered patterns is much more effective in reducing flow rate than any other pattern for the same number of plants.

Vegetative Buffer Strips --

Both natural and seeded vegetative strips have been recommended for filtering runoff from a variety of disturbed areas. EPA (1976) recommends use of both natural and installed buffer strips downslope from areas disturbed by mining. Brush barriers are recommended by Dallaire (1976) as a means of controlling erosion losses from construction sites.

Ohlander (1976) discussed sediment trapping by a vegetative strip such as might exist below a road drainage outlet. A regression model was developed which defined the filter effectiveness in terms of slope, soil stability, and a soil cover complex index.

The use of grass filter areas to improve the quality of runoff polluted by manure has received widespread attention during the last few years. Bingham (1978), Norman (1978), Khallel (1979), Doyle and Stanton (1977), Young (1978), and Vanderholm and Dickey (1978) are some of the individuals responsible for grass filter research. However, the recommendations presented by these studies are only gross estimates and do not include the physical basis necessary for developing prediction equations. These empirical studies were based primarily on monitoring results from a limited variety of conditions, were restricted to mild slopes, and did not consider variations in particle diameter.

Wilson (1967) studied the effectiveness of grass to filter sediment from flood waters. Results indicated that an inverse relationship exists between the filtration length to produce a maximum concentration of a given particle size in the deposited sediment and the diameter of that particle size. Thus, smaller particles require longer filters for maximum deposition than larger particles. Visual observation at the beginning of the next growing season of the Bermuda grass used in the tests seemed to indicate no growth inhibition due to deposited sediment. Wilson concluded that filter length, initial sediment concentration, flow rate, slope, grass height, grass density, and degree of submergence are interrelated factors affecting sediment removal. Grasses selected for filtration should have deep root systems to resist scouring if swift currents develop. In addition, these grasses should possess dense top growth, resistance to flooding and drought, and the ability to recover growth subsequent to inundation with sediment. The ability to yield economic returns either through the production of seed or hay would also be advantageous. However, Wilson does not provide a method for estimating the relationship between these parameters.

A rainfall simulator study conducted by Neibling and Alberts (1979) indicated the potential effectiveness of grass filtration. Sod strips as short as 0.61 meters reduced sediment discharge rates by more than ninety (90) percent, and sediment discharge of particles less than 0.002mm through the 0.61 meter strips was reduced by thirty-seven (37) percent. Neither empirical nor theoretical relationships were presented which could be used to estimate the influence of the various parameters on outflow conditions.

A new filter arrangement was proposed by Kao, et al. (1975) to solve the problems of sediment inundation and killing of the vegetation. The filter alternated grass strips with bare ground strips. Test results indicated that, when appropriate width-ratio of the grass to bare ground strips is chosen, filter efficiency remains high and the trapped sediment is retained in the bare ground region. This arrangement also lends itself to construction of filters which may be cleaned as the sediment deposits reach unsatisfactory depths.

Research has been conducted at the University of Kentucky to develop relationships which may be used to predict the amount of sediment trapped in a vegetative filter and the quality of the outflow. In laboratory studies without infiltration, the research indicated that mechanical settling alone can trap the coarse silts and sand size particles, but that the finer silts and clays pass through the filter. In field studies where infiltration was important, it was apparent that the outflow sediment load was reduced by infiltration, since the infiltrating water carried with it a sediment load equal to the suspended sediment concentration times the mass of water infiltrated. Thus, infiltration in vegetative filters decreases the sediment load of the clay and fine silt fraction, while the mechanical filtering action of vegetation filters the coarse silts and sands.

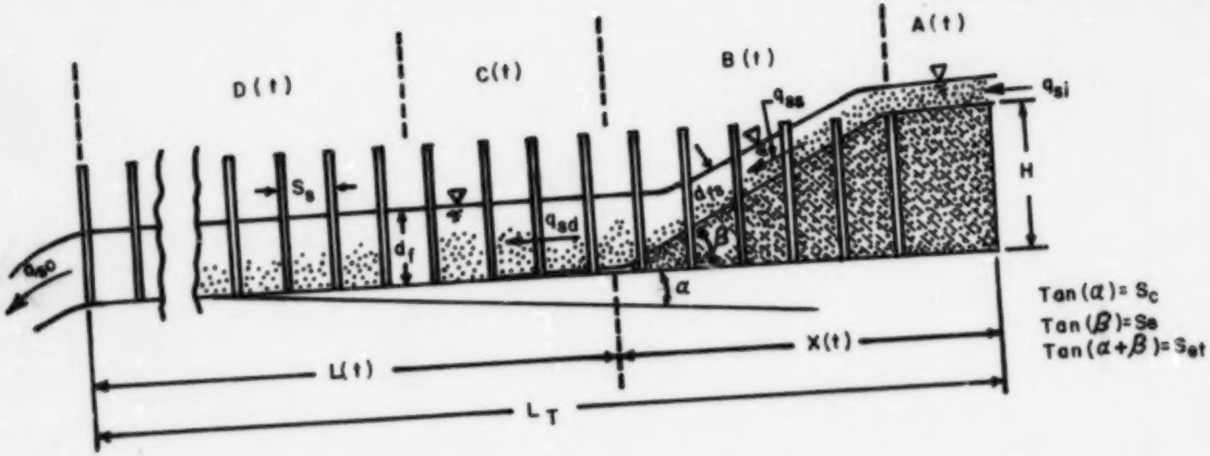
Sediment Transport Within Vegetation --

Research conducted at the University of Kentucky sought to quantify conditions within a vegetative filter as well as downstream from the filter. The objective of this work was to characterize outflow sediment load as a function of readily available inflow parameters and/or filter dimensions.

Description of Sedimentation Process Within Vegetation -- A conceptual model of the sedimentation process as observed by Barfield (1978) is presented in Figure 2. As sediment laden flow impinges a grass filter, its velocity is retarded and its transport capacity reduced. If the transport capacity is less than the inflow sediment load, sediment is deposited at the inlet of the filter media. This deposition causes the channel slope to increase, with a resulting increase in velocity and sediment transport capacity down the deposition face.

As shown in Figure 2, the filter is divided into four zones. The location of the transition from one zone to another moves downstream with time; hence, the location of each zone is denoted as a function of time. In zone A(t), transport occurs along the top of the inundated media, with essentially all of the incoming sediment being transported. Sediment is deposited uniformly along the deposition front in zone B(t), with the slope of this front being referred to as the equilibrium slope. In zones C(t) and D(t), the assumption is that the tractive force is less than the critical value for the original channel bed. In section C(t), sufficient sediment has been deposited on the original channel bed so that all surface irregularities are filled, allowing sediment to be transported as bed load. In zone D(t), an insufficient amount of material has been deposited on the bed to fill the irregularities so that all sediment reaching the bed is trapped. Since the location of the zones change with time, both the transport and location of each zone must be modeled after a given time of flow duration.

Infiltration effects are reflected by either an increase or decrease in flow rate, depending on the quantity of flow left after infiltration in zone D(t). The changed flow rate


D(t)
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B(t)
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q_{si}
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d_f
q_{sd}
d_{ts}
β
α
q_{so}
$Tan(\alpha) = S_c$
$Tan(\beta) = Se$
$Tan(\alpha + \beta) = S_{et}$
X(t)
L(t)
L_T

ZONE A(t); INITIAL INPUT WITH HEAVY SEDIMENT CONCENTRATION.

ZONE B(t); DEPOSITION OCCURS UNIFORMALLY WITH DISTANCE ON A DEPOSITION WEDGE.

ZONE C(t); SUFFICIENT DEPOSITION ON THE BED SO THAT BED LOAD TRANSPORT OCCURS, BUT THE CHANNEL SLOPE IS NOT CHANGED.

ZONE D(t); INSUFFICIENT DEPOSITION ON THE BED TO HAVE BEDLOAD TRANSPORT. ALL SEDIMENT REACHING BED IS TRAPPED.

THE LOCATION OF THESE ZONE ARE FUNCTIONS OF TIME.

Figure 2. Schematic of the sediment deposition process in erect media

will in turn be reflected by a comparable change in mean flow velocity and in transport capacity. This can be modeled with one of the many relationships available for infiltration along with the continuity equation.

The model development has evolved from a model for steady-state flow, with homogeneous sediment on uniform slopes, to a model with non-steady-state flow, with non-homogeneous sediment, on non-uniform slopes. Because of its simplicity, a description is first given of the uniform slope case and a subsequent description given for the more complex case.

Steady-State, Homogeneous Sediment, Uniform Slope Model -- In order to understand the mechanisms illustrated in Figure 2, it is necessary to look first at zone D(t). In this zone, insufficient material has reached the bed for bed load to occur so that all material reaching the bed is assumed to be trapped. Using probabilistic reasoning, Tollner et al. (1976) showed that the fraction of sediment trapped in zone D, $(q_{sd}-q_{so})/q_{sd}$, could be predicted from the effective filter length, L(t), flow depth, d_f,' flow velocity, V, settling velocity, V_s, and grass spacing, S_s, as given by equation (1-2) in Table 1.

By assuming an analogy between flow in a filter medium and that in a rectangular channel of width S_s and depth d_f, Manning's equation was modified to calculate flow velocity and depth of flow. Using these values in equation (1-2), the value of the outflow sediment load q_{so} can be calculated for a given fall velocity, if the effective filter length and sediment load into zone C(t), q_{sd}, is known.

In order to calculate a value for q_{sd}, sediment transport relationships were needed for flow in a filter. Tollner et al. (1978) modified Einstein's and Graf's transport and shear parameters (Graf, 1971) to account for the presence of vegetation, and also calibrated these equations for flow in a filter medium. Either of these equations can be used to predict a value for q_{sd}. Einstein's equations were chosen because of their widespread use.

The calculation of the effective filter length, L(t), requires a prediction of how the deposition profile advances with time. When a sediment-laden flow is introduced into vegetation, the flow depth increases and velocity decreases because of the retarding effect of the vegetative elements. The decreased flow velocity results in decreased sediment transport capacity. If the sediment transport capacity is then sufficiently less than the input sediment load, deposited

TABLE 1. SUMMARY OF THE FLOW AND TRANSPORT EQUATIONS FOR STEADY-STATE, HOMOGENEOUS SEDIMENT

Zone D(t)

Sediment Trapping

$$\frac{q_{sd} - q_{so}}{q_{sd}} = \exp\left[-1.05 \times 10^{-3} \left(\frac{V_s R_s}{\gamma}\right)^{0.82} \left(\frac{VL(t)}{V_s d_f}\right)^{-0.91}\right] \qquad (1\text{-}2)$$

Flow

$$V = \frac{1}{n} R_s^{2/3} S_c^{1/2} \qquad (1\text{-}3)$$

$$R_s = \frac{S_s d_f}{2d_f + S_s} \qquad (1\text{-}4)$$

$$q_w = Vd_f \qquad (1\text{-}5)$$

Zone C(t)

Flow - Same as Zone D(t)

Sediment Transport

$$\frac{\gamma_s - \gamma}{\gamma} \frac{d_p}{S_c R_s} = 1.08 \left[\frac{q_{sd}}{\gamma_s \sqrt{\frac{\gamma_s - \gamma}{\gamma} g d_p^3}}\right]^{-0.28} \qquad (1\text{-}6)$$

Zone B(t)

Rate of Advance

$$t_* = \frac{H^2 \gamma_{sb}}{2f q_{si} S_c} \qquad (1\text{-}7)$$

$$X(t) = \left[\frac{2f q_{si} t}{\gamma_{sb} S_c}\right]^{1/2} \quad , t < t_* \qquad (1\text{-}8)$$

$$X(t) = \frac{f q_{si} (t - t_*)}{H \gamma_{sb}} + X(t_*) \; , t > t_* \qquad (1\text{-}9)$$

$$f = \frac{q_{si} - q_{sd}}{q_{si}} \qquad (1\text{-}10)$$

$$S_e = S_{et} - S_e \qquad (1\text{-}11)$$

Sediment Transport

$$q_{ss} = \frac{q_{si} + q_{sd}}{2} \qquad (1\text{-}12)$$

$$\frac{\gamma_s - \gamma}{\gamma} \frac{d_p}{R_{ss} S_{et}} = 1.08 \left[\frac{q_{ss}}{\gamma_s \sqrt{\frac{\gamma_s - \gamma}{\gamma} g d_p^3}}\right]^{-0.28} \qquad (1\text{-}13)$$

$$R_{ss} = \frac{S_s d_{fs}}{2d_{fs} + S_s} \qquad (1\text{-}14)$$

$$q_w = V_{ss} d_{fs} \qquad (1\text{-}15)$$

$$V_{ss} = \frac{1}{n} R_{ss}^{2/3} S_{et}^{1/2} \qquad (1\text{-}16)$$

particles will form a triangular shaped wedge. If this continues with constant inflow conditions, the deposition wedge will approach the same height as the vegetation at time t_*. At this height, the wedge will flatten out, but continue to advance downstream at approximately a constant angle, as shown in zones A(t) and B(t) of Figure 2. By performing a mass balance after the slope of the deposition wedge, S_c, is known, the advance distance can be computed using either equation (1-8) or (1-9), depending on the time. The value of S_c can be calculated from the modified Einstein and Manning equations mentioned previously. A summary of the flow and transport equation is given in Table 1 for the steady-state case.

Unsteady-State, Non-Homogeneous Sediment Solution -- For situations where the inflow rate and/or concentration is changing, Hayes et al. (1979a) extended the steady-state, homogeneous sediment solution by integrating the differential equations defining the advance distance X(t) in zone B(t) of Figure 2. The values of f, q_{si}, and S_e are averaged over a time interval $(t_f - t_i)$ to obtain t_*. The incremental change in distance is added to the initial advance distance $X_i(t)$ to obtain the advance distance, $X_f(t)$, after the time interval. Equations (1-8) and (1-9) in Table 1 will be replaced by these equations for unsteady-state flow or:

$$X_f(t) = \left[\frac{2}{\gamma_{sb}}\left(\frac{f\, q_{si}}{S_e}\right)(t_f - t_i) + X_i(t)^2\right]^{1/2} \quad \text{for } t<t_*$$

$$X_f(t) = \left[X_i(t) + (t_2 - t_1)\left(\frac{f\, q_{si}}{H\, \gamma_{sb}}\right)\right] \quad \text{for } t>t_*$$

The other equations will remain the same as for the steady-state case.

The design equations were further extended for the non-homogeneous particle size distribution by subtracting a portion of the particle distribution curve, based on what has been trapped in previous zones and utilizing the previous unsteady flow equations. The representative particle size for zones A(t) and B(t) is calculated by selecting the average size of particles greater than 0.037 mm in diameter. The smaller particles are not included, since observation indicates that few of these particles can be trapped in zones A(t) and B(t). After calculating the transport capacity of zone C(t), the fraction trapped in zones A(t) and B(t) can be found. The remaining fraction of these sizes is then used as an input sediment load into zone D(t), and equation (1-2) is used to calculate the fraction of these particles entering zone D(t) which are trapped. The settling velocities for the 0.004 and 0.037 mm particles size range is also calculated and substituted into equation (1-2) to obtain the fraction of this size range trapped. It was also assumed that those particles less than 0.004 mm would not be trapped. Thus, by adding the portion less than 0.004 mm, the portion remaining between 0.004 and 0.037 mm, and the portion remaining greater than 0.037 mm, the total trapping efficiency of the filter can be calculated.

Effects of Upstream Deposition on Sediment Load -- The aforementioned analyses consider the transport capacity within the vegetative medium, but do not consider the possible effect upstream trapping may have on sediment load. Work reported by Neibling and Alberts (1979) indicates that there may be significant trapping in this area. To incorporate this component into the design procedures, Hayes et al. (1981) utilized a mass balance to calculate the sediment trapped in this region. The depth of deposition, Y(t), has previously been estimated by:

$$Y(t) = \left[\frac{2\ fq_s}{\gamma_{sb}} \ S_{et} \right]^{1/2}$$

The above equation is solved at two different times, t_1 and t_2 less than $t_\star$, while assuming that the deposition wedge profile extends upstream horizontally until it intersects the channel bottom; then the sediment load reaching the filter, q_{si}, can be calculated by:

$$q_{si} = q_s - \left[\frac{Y_2{}^2 - Y_1{}^2)\ \gamma_{sb}}{2\ S_e\ (t_2 - t_1)} \right]$$

where q_s is the initial sediment load. The above equation is the model for predicting the effects of upstream deposition on the sediment load.

Accounting for the Effects of Infiltration -- Where infiltration is significant, the quasi steady-state system shown in Figure 2 becomes a spatially varied flow problem. The model was adapted for this situation by making the following assumptions:

1. The infiltration throughout the filter length is steady-state so that flow rate decreases linearly from the upstream to the downstream end.

2. The sediment contained in the water infiltrated in zones C(t) and D(t) is carried with that water and trapped as it reaches the channel bottom or enters

the soil profile (Figure 2).

3. The sediment contained in the water infiltrated in zone A(t) and B(t) is not trapped because of the higher flow velocity on the deposition wedge.

4. The sediment transport in each zone can be characterized by the average hydraulic and sediment conditions which exist in that zone.

5. Upstream trapping was insignificant because of the break in slope where the inlet connected to the filter.

Accounting for Time Lag of Outflow -- In order to account for the time lag between inflow and outflow, outflow conditions were lagged behind inflow conditions by a time interval equal to the flow time through the filter.

Experimental Evaluation of Kentucky Model

Evaluations of the Kentucky Model were conducted in laboratory flumes, using artificial media and real grasses, and in field channels on real grasses. It is impossible to control parameters such as media spacing and media size with real grasses. For this reason, artificial media were constructed and used to develop the basic relationships and calibration coefficients previously mentioned. These relationships were first evaluated on real grasses in specially constructed 15.2 meters laboratory flumes. For the laboratory studies, infiltration was not a factor. Results of the laboratory tests indicated good agreement between observed and predicted results for four of the five laboratory tests. A valid explanation could not be found for the poor prediction of the fifth test. Complete results are presented by Hayes et al. (1981).

Five field tests were also run on real grasses in which infiltration was significant. Pertinent parameters are shown in Table 2 for each of the tests run. Sediment was generated from an erosion table on which shale overburden from a surface mine in Western Kentucky was subjected to simulated rainfall. Good agreement was found between predicted and observed results in all five of the tests. Typical test results are shown in Figures 3 and 4 for Test 1. Complete results are available in Hayes et al. (1981).

The results of these previous experimental evaluations indicate that the Kentucky Model can be used to predict the performance of vegetative filters in the field. Barfield et

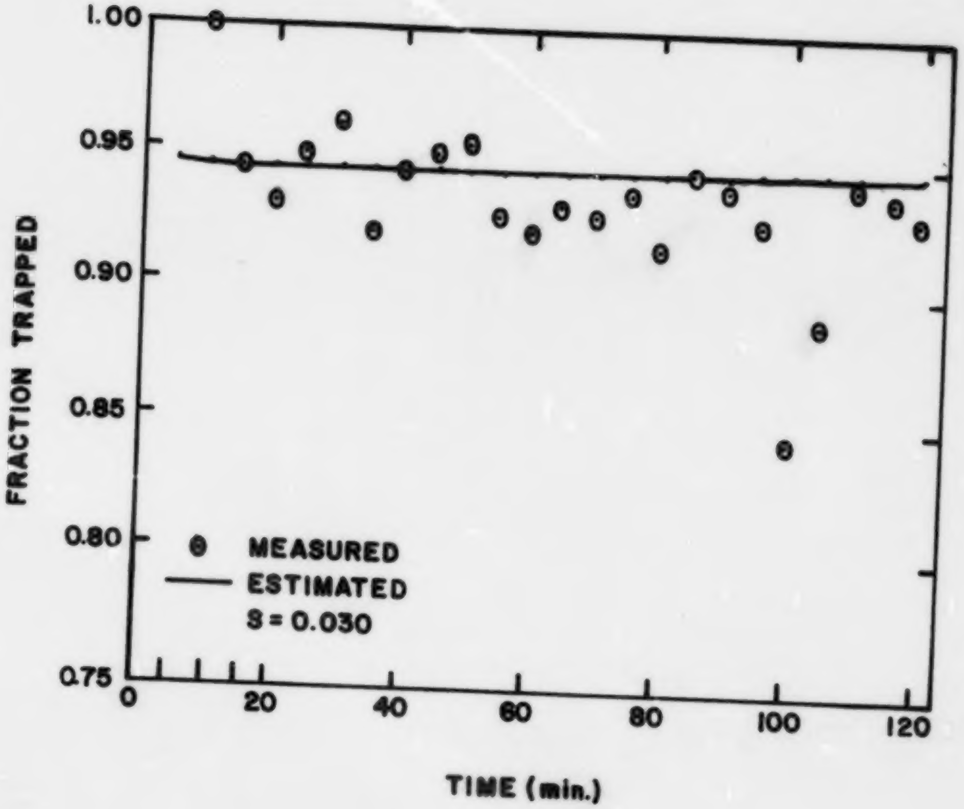


Figure 3. Fraction trapped versus time for field test 1 (Hayes et al 1981)

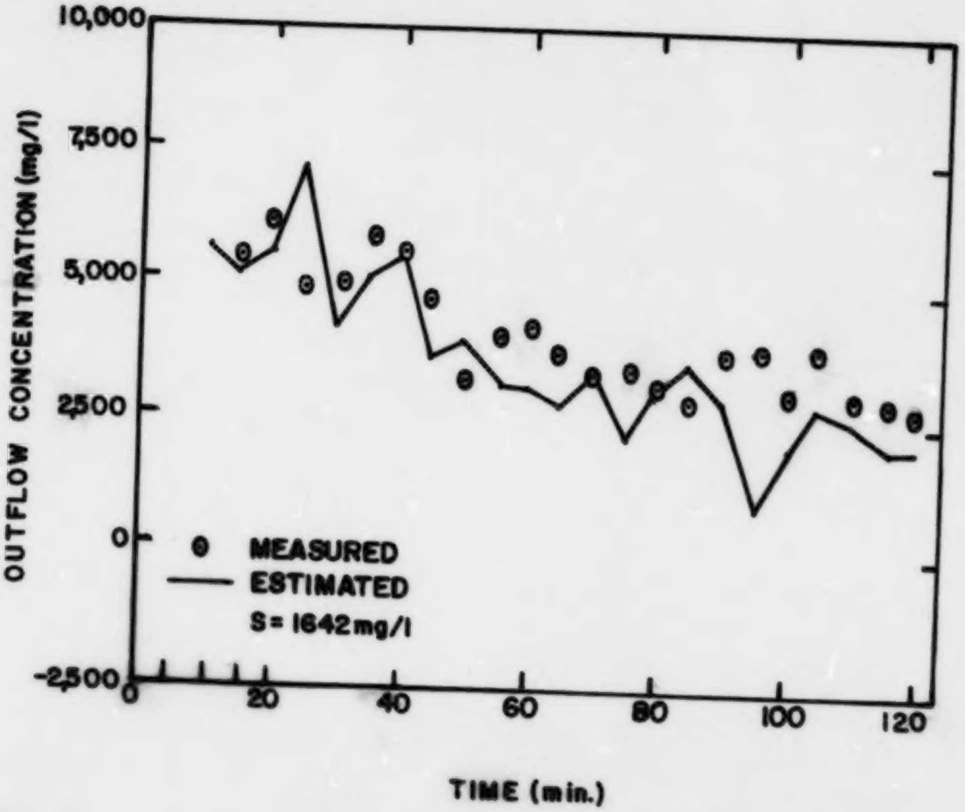


Figure 4. Outflow concentration versus time for field test 1 (Hayes et al 1981)

TABLE 2. PARAMETERS FOR FIELD TESTS

Test No.	Slope (%)	Media Spacing (cm)	Flow Rate (cm^3/ac/cm)	Sediment Concentration (mg/l)	Type Vegetation	Plot Length (m)
1	2.86	1.96	38.8	681,000-246,000	Fescue2/	28.8
2	3.0/6.01/	1.73	33.9	4,900- 13,000	"	18.3/14.81/
3	3.0/6.0	1.73	29.4	23,000- 4,200	"	18.3/14.8
4	9.6/9.9	1.34	36.2	45,000- 4,000	"	17.1/16.8
5	9.6/19.9	1.34	36.2	19,000- 4,600	"	17.1/16.8

Plot width = 15.4 cm

Test duration = 2 hr.

1/ Segment 1/ Segment 2

2/ Numerous weeds also present

al. (1980) indicated that the following limitations should be kept in mind when using the model:

1. Difficulties in estimating the exact value of the roughness coefficient require that conservative values of Manning's n be used for design purposes. Conservative values of grass spacing should also be selected for design purpose, since this characteristic cannot be measured until the vegetation is well established.

2. The depth of deposition in section D(t) at which the vegetation ceases to operate as a filter has not been determined experimentally. Further research is needed to develop methods to predict this variable.

Although the Kentucky studies indicate that vegetative filters can operate to trap up to ninety-nine (99) percent of sediment under carefully controlled conditions, additional study was needed of the performance of vegetative filters under natural conditions. Such a study is the subject of the remainder of this report.

LEGISLATION, FUNDING, AND SITE SELECTION

Legislation

The Kentucky General Assembly created the Department for Natural Resources and Environmental Protection in 1974, enacting Kentucky Revised Statue 224. Responsibilities of the Department include administration of functions relating to conservation, maintenance, and preservation of land and water resources, and the prevention, abatement, and control of all water, land, and air pollution. The Department is headed by a Secretary who is responsible for overall departmental administration.

The Department's Bureau of Surface Mining Reclamation and Enforcement (BSMRE) is vested under KRS 350 to regulate and control the surface mining of coal in order to minimize resultant safety and environmental hazards to the people and resources of the Commonwealth. The Bureau, under the supervision of the Secretary and its Commissioner, has the following authority and powers relative to this project study:

- o To exercise general supervision and administration and enforcement of KRS 350 and all rules, regulations, and orders promulgated thereunder;

- To encourage and conduct investigations, research, experiments, and demonstrations and to collect and disseminate information related to strip mining;

- To adopt, without hearing, rules and regulations relative to the filing of reports, the issuance of permits, and other matters of procedure and administration;

- To examine and pass upon all plans and specifications submitted by the operator for the method of operation, backfilling, and grading and for the reclamation of the area of land affected by his operation.

Existing Sandards --

All surface mining operations in the Commonwealth of Kentucky must be permitted through the Bureau of Surface Mining Reclamation and Enforcement. Permit requirements are described under KRS 350.060. Operators are also required to submit a drainage plan along with permit applications. Directional flow of water, constructed drainways, natural waterways used for drainage, and the streams or tributaries receiving any discharges must be diagrammed. In addition, KRS 350.090 requires operators to prepare and enact a reclamation plan for land affected by mining operations. KRS 350.090 reads (in part) as follows:

> KRS 350.090 Method of operation and reclamation plan -- Waste on permit area only. (1) Under the provisions of this chapter and regulations adopted by the department, an operator shall prepare and carry out a method of operation, plan of grading and backfilling and a reclamation plan for the area of land affected by his operation. In developing a method of operation, and the plans of backfilling, grading and reclamation, all measures shall be taken to eliminate damages to members of the public, their real and personal property, public roads, streams and all other public property from soil erosion, rolling stones and overburden, water pollution and hazards dangerous to life and property. The plan shall be submitted to the department and the department shall notify the applicant by certified mail, return receipt requested or by registered mail within thirty (30) working days after receipt of the plan and complete application if it is or is not acceptable.

The regulations which are applicable to KRS 350.090 and also particularly relevant to this project are:

- 405KAR 1:160, Protection of the Hydrologic System, requires that only minimum disturbances to the hydrologic system are permitted and that all surface openings be properly sealed.
- 405KAR 1:170, Water Quality Standards and Surface Water Monitoring, identifies the following water quality standards or effluent limitations emanating from mine sites:
    - pH between 6.0 and 9.0.
    - Iron concentrations not in excess of 7 mg/l.
    - If the pH is less than 6.0, or if the iron concentration is greater than 10 mg/l., then total manganese must be less than 4.0 mg/l.
    - Total suspended solids must not exceed 70 mg/l.

  In addition, 405KAR 1:170 specifies the methodology for surface water monitoring and the reporting procedures required by the operator.
- 405KAR 1:190, Diversion of Surface and Ground Water Flows, states that:
    - Diversion of overland flow may be allowed in order to minimize erosion and to prevent or remove water from contacting toxic producing deposits.
    - Diversions shall be designed and constructed to meet department specifications.
    - Stream buffer zones shall be observed within 100 feet of intermittent or perennial streams.
    - Discharge structures shall be constructed, where necessary to reduce erosion and prevent deepening of stream channels.
    - Surface waters shall not be discharged into underground mine working unless department approval is granted.
- 405KAR 1:200, Sediment Control Measures, specifies the various methods that may be used to control sediment, including vegetative sediment filters, as well as the design, construction and maintenance of sediment ponds.

Funding

This study was made possible through a cooperative agreement from the U. S. Environmental Protection Agency (EPA) to the Bureau of Surface Mining Reclamation and Enforcement, Kentucky Department for Natural Resources and Environmental Protection. The Bureau of Surface Mining Reclamation and Enforcement (BSMRE) contributed five (5) percent matching funds to the study.

The Environmental Protection Agency's authority to fund the study is contained in Section 107 "Mine Water Pollution Control Demonstrations" of the Federal Water Pollution Control Act Amendments of 1972, P.L. 92-500. Section 107 authorizes EPA to make grants for projects to demonstrate valuable approaches eliminating or controlling mine water pollution resulting from active or abandoned mining operations.

The Kentucky Bureau of Surface Mining Reclamation and Enforcement is allowed to accept Federal grants and other funds in accordance with the KRS 350.150 and 350.163.

All money received by the Kentucky Department for Natural Resources and Environmental Protection through the payment of fees, forfeiture of bonds, and Federal grants is placed in the State Treasury. A general fund is appropriated to the Department on a bi-annual basis as approved by the Kentucky General Assembly. Funds are expended (under supervision of the Bureau Commissioner) for the administration and enforcement of KRS 350 and for the reclamation of improperly reclaimed surface-mined lands.

Site Selection

The search for a suitable study site was initiated immediately after award of the project contract.

Several mine operations in Eastern Kentucky were considered and evaluated before on-site visits were made to investigate and determine if a particular area and operation was suitable to project study requirements. Site selection criteria included the following:

- Availability of a study area adjacent to an area disturbed by surface mining.
- Physical characteristics (i.e., slope and soil conditions) typical of mined areas.
- Comparable time frames for mining land lease and the scheduled project completion date.
- Complete cooperation from the mining company and;
- accessibility to the study site by project personnel under all weather conditions.

The contour and mountaintop mining operation being conducted by the Savoy Coal Company near Williamsburg, Kentucky, met all site selection criteria. The project area selected was directly below coal reserves planned for mining. The area was under lease and would so remain for the duration of the project study.

Additionally, both the physical characteristics of the land and the existing soil conditions were calculated to provide the parameters needed to obtain an accurate assessment of the vegetative establishment procedures to be evaluated in the project study.

The Savoy Mining Company was responsive, assured complete cooperation, and was quick to supply needed preliminary information.

DESCRIPTION OF PROJECT SITE

The study site chosen for the demonstration project (Figure 5) is located on the western edge of the Appalachian Plateau physiographic region in Southeastern Kentucky. This specific demonstration site is approximately 12.9 Kilometers south of Corbin, Kentucky, in an area locally known as Buttermilk Hollow.

Drainage for the project area is in the Eaton Branch watershed, which flows east for approximately 2.8 Kilometers before entering Camp Creek. Camp Creek flows north to northwest until entering the Laurel River 3.2 Kilometers northwest of Corbin.

The Laurel River watershed area is characterized by a dendritic drainage pattern and U-shaped valley bottom, with well developed valley bottoms in larger streams.

The region is characterized by moderate to steeply sloping hills, with elevations exceeding 762 meters in the eastern portion of the region. In the immediate area of the vegetative filter site, the slopes are moderate, with elevations ranging from 310.9 meters north of Corbin to 518.2 meters immediately north of the site.

The area surrounding the study site is typically composed of woodlands and pasture contained on small farms. Although the area is composed of these small farming operations, the largest industry, by far, is the mining of coal.

The study area was located directly below a contour strip bench and outslope created by previous mining activities. This sparsely vegetated outslope area was highly suitable because it provided the primary drainage for the project site.

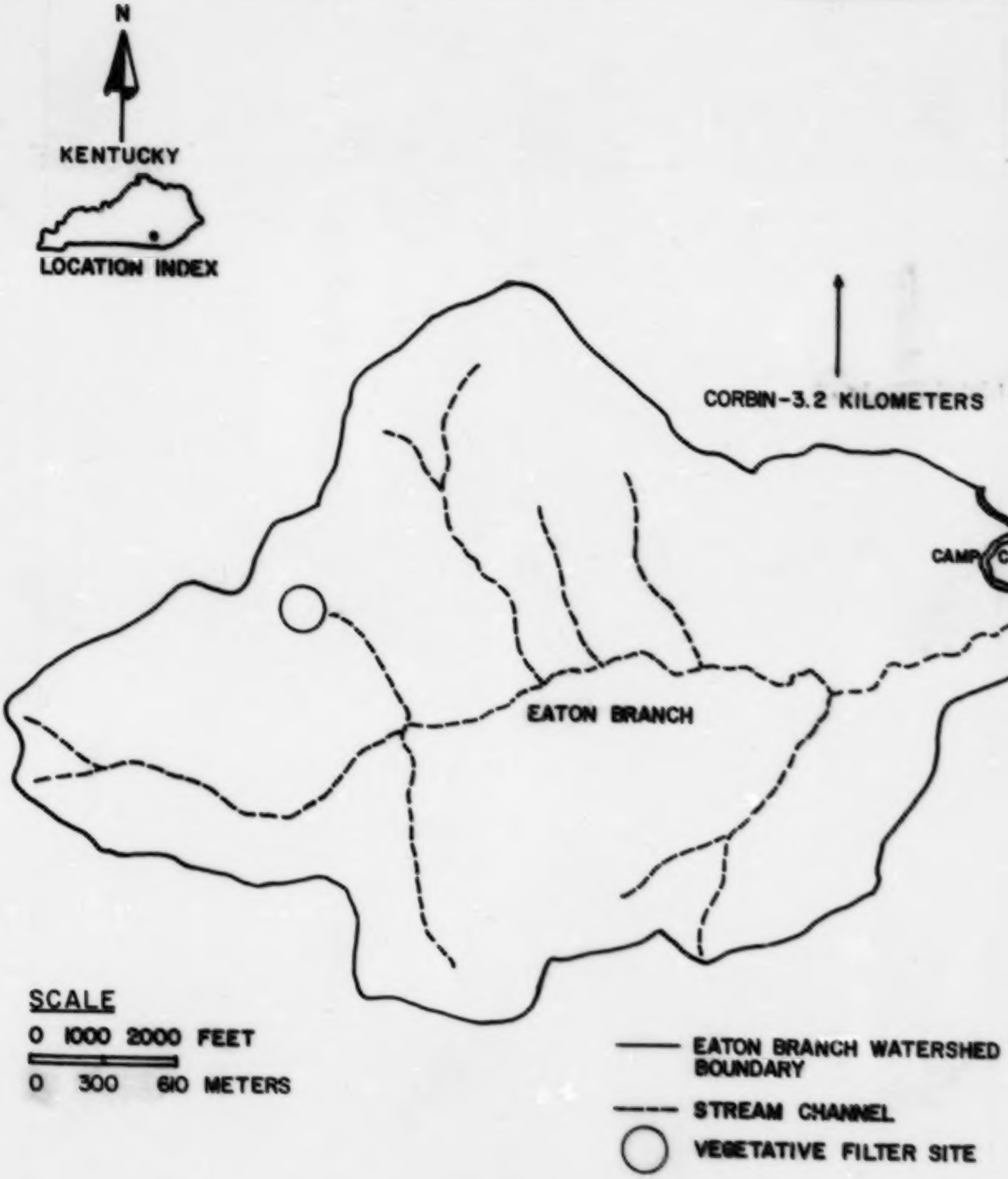

N
KENTUCKY
LOCATION INDEX
CORBIN-3.2 KILOMETERS
CAMP CREEK
EATON BRANCH
SCALE
0 1000 2000 FEET
0 300 610 METERS
EATON BRANCH WATERSHED BOUNDARY
STREAM CHANNEL
VEGETATIVE FILTER SITE

Figure 5. Site location map

PROJECT OBJECTIVES AND APPLICATIONS

Previous studies have shown that vegetative filters have the potential to substantially reduce sediment yield from disturbed areas. Their effectiveness had not been evaluated under field conditions with natural rainfall and repeated sediment loadings. In order to make this evaluation, the project had as its objectives:

1. The establishment of a vegetative filter as close as possible to a sediment source on a surface mined area.

2. The collection of water quality and sediment data at the filter for a one-year period.

SECTION 4

PRELIMINARY SITE CONDITIONS AND VEGETATIVE FILTER DESIGN

GEOLOGY AND MINING OF THE PROJECT SITE

Geology

Stratigraphically, the vegetative filter site is located in rock of the Breathitt Formation of the Middle Pennsylvanian age. Typical of the Pennsylvania coal-bearing measures of Kentucky, the strata consists of shales, sandstones, siltstones, coals, ironstone, and clays. Individual lithotypes tend to be discontinuous and irregular, both vertically and laterally, often intertonguing with adjacent strata. The coal seams generally are the most laterally persistent lithotypes and, therefore, are often the only beds that could be considered regional aquifers.

The specific rock types underlying and adjacent to the project site are predominantly shales with sandstones, three coal seams, and their associated underclays. In order of proximity to the surface, mineable coal is found in the Moss coal bed, the Jellico coal bed, and the Blue Gem coal bed. All three coal seams are located above the elevation of the project site. There are no major structural features in the area. Localized structural highs and lows are present, and there is a slight dip of the strata toward the southeast.

Mining

The area surrounding the study site was mined by both contour and mountaintop removal methods. The abandoned area above the study site was contour mined 20 years previously, but not all the coal in this area was removed.

The primary coals of mineable thickness in the area are contained in the Blue Gem, Jellico, and Moss coal beds. These seams are mined extensively throughout the area. Mined areas above the project site are shown in Figure 6.

SOIL CONDITIONS

Soils located in the vegetative filter area are contained in the Muse-Wellston-Trappist association. The study area

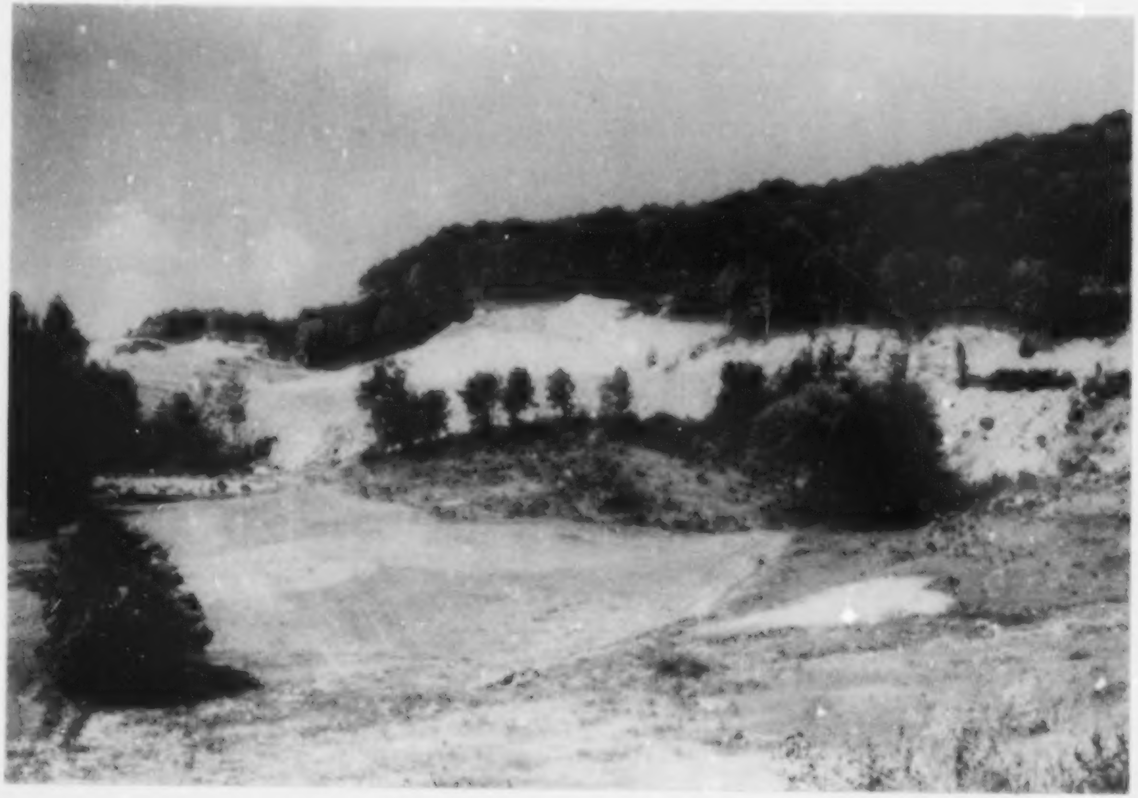


Figure 6. Previously mined areas above the project site

is predominantly composed of natural soil, although some spoil material pushed over the outslope is evident in the upper portion of the area. Part of the area is devoid of topsoil, due primarily to erosion of unvegetated areas.

This soil association consists of soils on broad, narrow, rounded ridgetops and on convex side slopes. Likely position for this soil is along temporary drainageways of intermittent streams. The dominant material in the area is shale, but some sandstone can be found.

Typically, the following percentages of each series are found in the described areas:

- Muse - 60 percent
- Wellston - 20 percent
- Trappist - 10 percent
- Minor soils - 10 percent (Clymer, Dekalb and Tate series)

This particular association of soils is very highly dissected, with streams generally 70 meters below the ridge tops.

The Muse and Trappist soils are found on side slopes, narrow ridgetops, and small knobs on broad ridgetops. The Wellston soils are commonly found on broad, smooth to slightly convex ridgetops.

Muse, the major soil series found in the area, is formed from residuum that weathered from interbedded acid shale and thin sandstone, or colluvium transported down from soils derived from shale.

The Muse soils have thick root zones, and are strongly acid and moderate to low in natural fertility. In the study area the profile consists of a surface five (5) centimeters of very friable brown silt loam over 15 centimeters of friable, yellowish-brown silty clay loam.

A typical profile of a Muse silt loam includes:

A1--0 to 5 centimeters, brown silt loam; weak, fine, granular structure; friable; 1 percent of the volume is shale fragments less than 1/4 inch across; very strongly acid; abrupt, wavy boundary.

A--5 to 20 centimeters, yellowish-brown light silty clay loam; weak, fine, subangular blocky structure that breaks to weak, fine granular; friable; 1 percent of the volume is shale fragments less than 1/4 inch across; very strongly acid; clear, wavy boundary.

B1--20 to 33 centimeters, yellowish-brown silty clay loam; weak, fine and medium, subangular blocky structure, friable; 3 percent of the volume is shale fragments 1/4 inch to 1-1/2 inches across; very strongly acid; clear, wavy boundary.

B21t--33 to 51 centimeters, strong-brown heavy silty clay loam; weak fine, subangular blocky structure; friable; faint, patchy clay films in pores; 5 percent of the volume is shale fragments 1/8 inch to 1 inch across; very strongly acid; gradual, wavy boundary.

B22t--51 to 76 centimeters, yellowish-red silty clay; moderate, fine, subangular blocky structure; friable, faint, patchy clay films in pores; 15 percent of the volume is shale fragments 1/4 to 1 inch across; very strongly acid; clear, smooth boundary.

B3t--76 to 117 centimeters, yellowish-red silty clay; common, fine faint varigations of yellowish red and light reddish brown; weak, very fine, subangular blocky structure; friable; faint, patchy clay films in pores; 20 percent of the volume is shale fragments 1/8 to 1/2 inch across; very strongly acid; gradual, irregular boundary.

C--117 to 178 centimeters, yellowish-red silty clay; common, fine, faint mottles of pinkish gray and reddish yellow; massive; firm; 20 percent of the volume is shale fragments 1/8 inch to 2 inches across; very strongly acid.

HYDROLOGIC DESIGN CONSIDERATIONS

Engineering tasks performed during the project can be grouped as: (1) development of a design storm; (2) design using the Kentucky Grass Filter Model; (3) selection of a filter design.

Development of a Design Storm

Runoff Hydrographs --

The development of a design storm involves the prediction of a runoff hydrograph and a sediment pollutograph. A map and cross-section of the contributing areas is shown in Figure 7. A runoff hydrograph was calculated for a two (2), five (5), and ten (10) year, twenty-four (24 hour storm using the SCS TR 55 Method (SCS, 1975). Computation procedures are provided in Appendix I, and the hydrographs plotted in Figure 8.

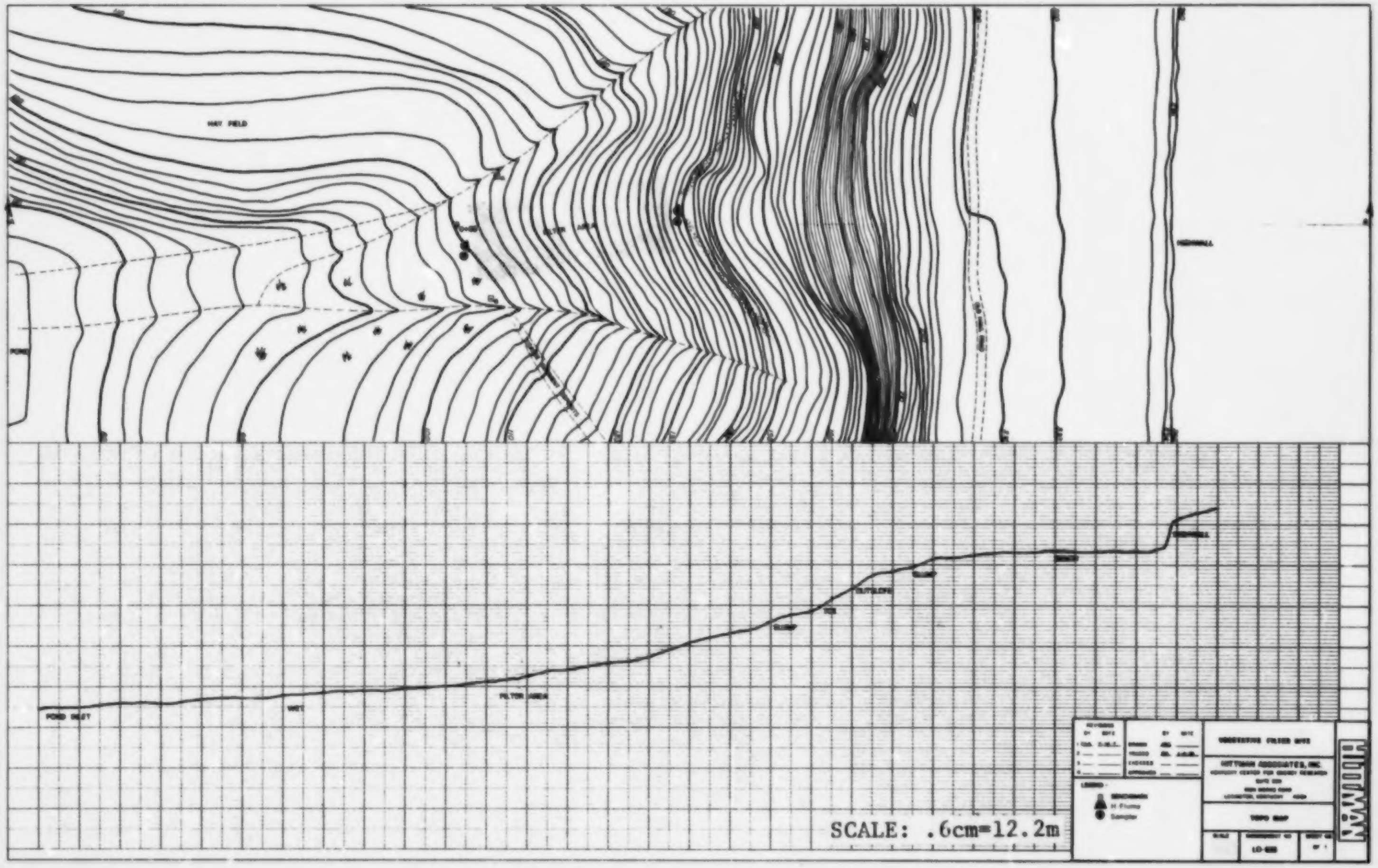

HAY FIELD
HIGHWALL
POND INLET
WET
FILTER AREA
OUTSLOPE
HIGHWALL
SCALE: .6cm=12.2m
LEGEND
TOPO MAP
HITTMAN

Figure 7. Map and cross section

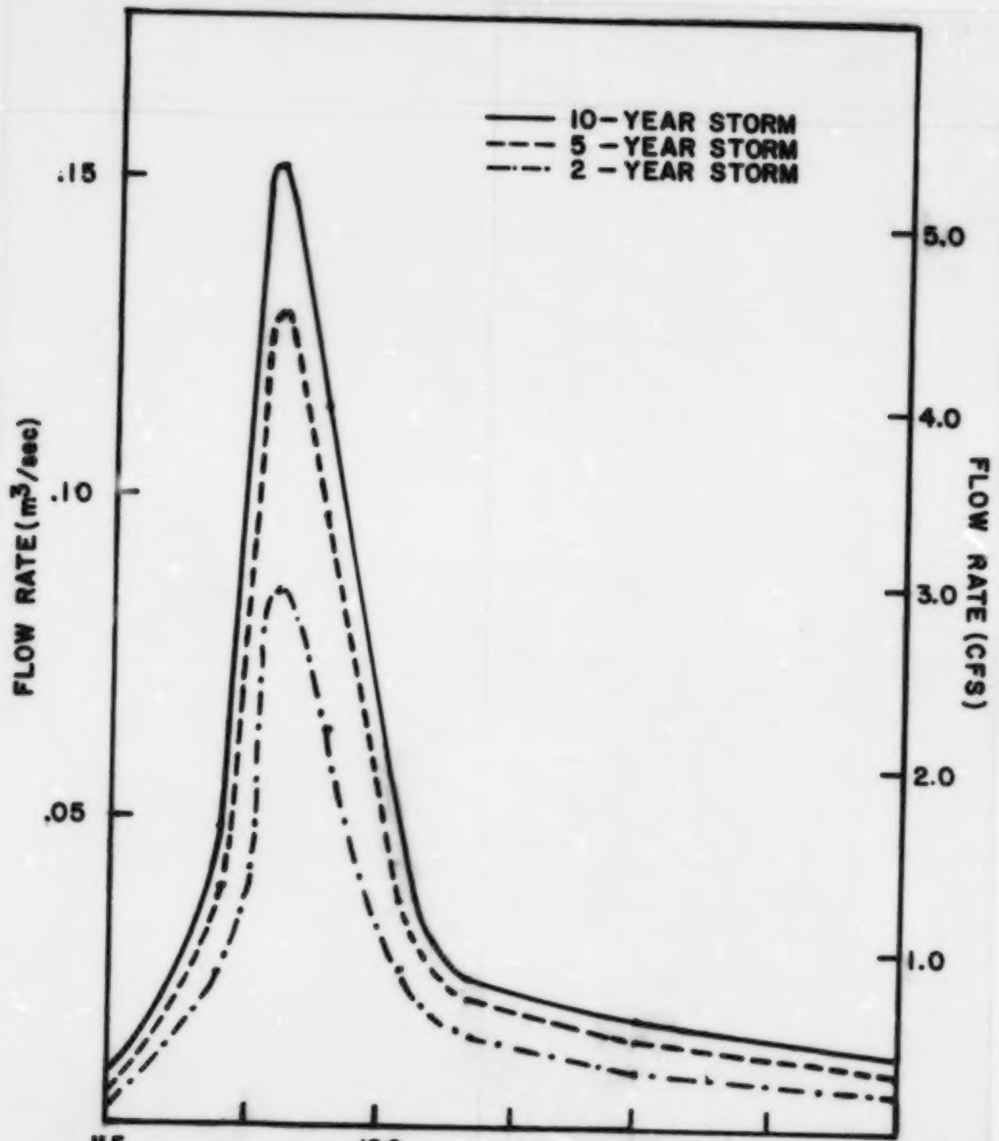


Figure 8. Runoff hydrograph for 2, 5 and 10 year storm

Pollutographs --

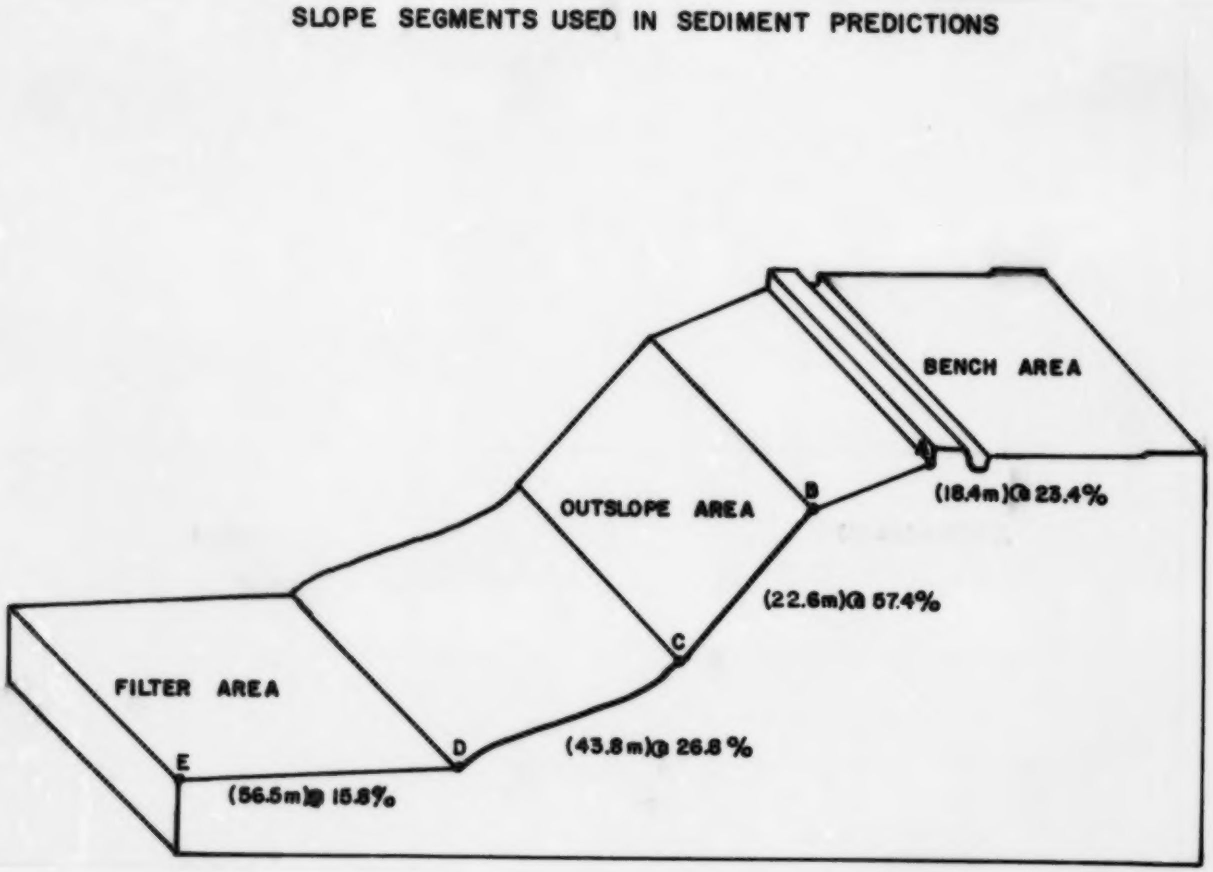
The development of sediment pollutographs is not as straightforward as the development of runoff hydrographs and no one computation procedure has gained widespread acceptance. In order to predict a pollutograph, the sediment yield must first be predicted. This yield is then distributed over a period of time and used in conjunction with a runoff hydrograph to develop a pollutograph.

Sediment Yields --

Several procedures are available for computing sediment yield. These procedures are summarized in Haan and Barfield (1978). Since the sediment source area for this study is a long, steep slope, a prediction procedure was needed to account for the possibility of deposition which might occur just prior to the grass filter. One procedure which takes this into account is the Deposition Modified Universal Soil Loss Equation (USLE) as given in Haan and Barfield (1978).

In order to make the sediment yield computations using the Deposition Modified USLE, the source area was divided into segments as shown in Figure 9. The sediment yield from the slope is then calculated according to the following procedure:

1. Determine the size distribution of sediment aggregates which will be eroded from each segment.
2. Determine the sediment detached from each segment, D_jt.
3. Divide the detached material into bedload and suspended load, D_jB and D_js. Calculate the material available for transport as that entering the segment plus that detached from the segment.
4. Calculate the bedload transport capacity of water exiting each section, Tcj.
5. Compare the total bedload material available for transport from each section with the material available for transport. The actual bed material exiting the section will be less than the transport capacity and the material available for transport.
6. Assume that suspended load is unaffected by narrow grass strips and mulches. Calculate



SLOPE SEGMENTS USED IN SEDIMENT PREDICTIONS

BENCH AREA
A
(18.4m)@ 23.4%
B
OUTSLOPE AREA
(22.6m)@ 57.4%
C
(43.8m)@ 26.8 %
D
FILTER AREA
E
(56.5m)@ 15.8%

Figure 9. Slope segments used in sediment predictions

the fraction of suspended load trapped only by long grass strips.

7. Repeat steps (1) - (6) for each segment.

A flow diagram of the computation process is shown in Figure 10.

Size Distribution of Eroded Sediment --

The probable size distribution of the eroded sediment was determined by subjecting samples of the source area soil surface material to simulated rainfall with an energy content similar to that of a 10-year, 24-hour storm and measuring the size distribution of the eroded sediment. This was accomplished by using an apparatus in which simulated rainfall was generated from a Spraying Systems 80-150 Nozzle, operating at 6 psi, (.42 Kg/cm^2) located at a height of ten feet above the sample. This arrangement will give a rainfall with an energy content similar to that of a storm with an average intensity greater than 0.6 in/hr (1.52 cm/hr.) (Williams, et al., 1978, Meyer and Harman, 1977). At the site selected for this study, the percent of 24-hour rainfall greater than 0.6 in/hr (1.52 cm/hr.) is shown in Table 3 (using as SCS Type II rainfall distribution). At intensities less than 0.6 in/hr (1.52 cm/hr.), the energy content of the simulated rainfall will be greater than that of natural rainfall; therefore approximately 37 to 40 percent of the rainfall will have an energy content greater than natural rainfall. The resulting effect on the size distribution of eroded sediment should be such that the eroded aggregates will be smaller than those generated by natural rainfall. The result of this input into the vegetative filtration model, to be discussed in a subsequent section, will be conservative in that it will underpredict the trapping efficiency.

The eroded sediment from the sample was directed into a sieve stack, with sizes ranging from No. 16 to No. 230. These sieves were gently washed five times to determine the percent of sediment in each size range. The particles passing the number 230 sieve were subjected to a pipette analysis to determine their size distribution. The tests were replicated four times and the size distribution plotted in Figure 11.

Sediment Detached from Slope Segment --

The sediment detached from any segment (j) during a design storm was calculated from the equation (Haan and Barfield, 1978):

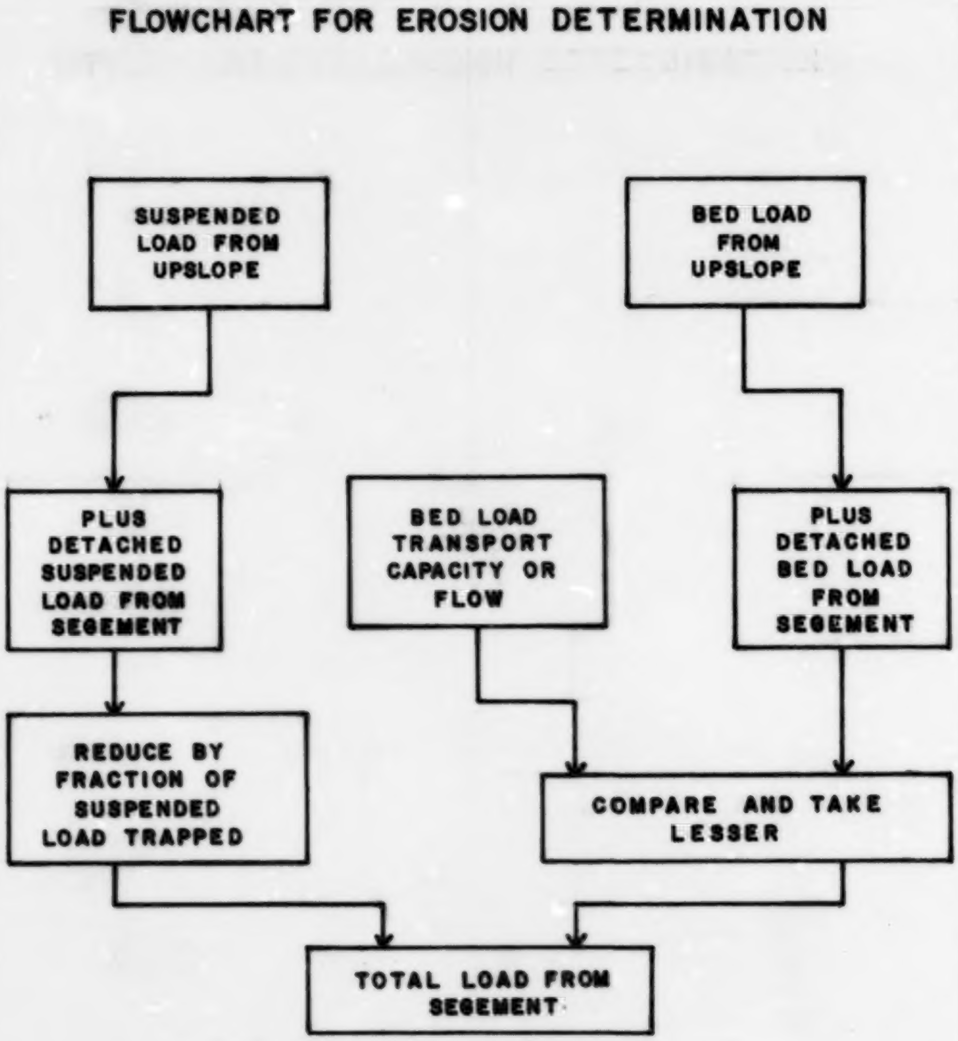

FLOWCHART FOR EROSION DETERMINATION
SUSPENDED LOAD FROM UPSLOPE
BED LOAD FROM UPSLOPE
PLUS DETACHED SUSPENDED LOAD FROM SEGEMENT
BED LOAD TRANSPORT CAPACITY OR FLOW
PLUS DETACHED BED LOAD FROM SEGEMENT
REDUCE BY FRACTION OF SUSPENDED LOAD TRAPPED
COMPARE AND TAKE LESSER
TOTAL LOAD FROM SEGEMENT

Figure 10. Flowchart for erosion determination

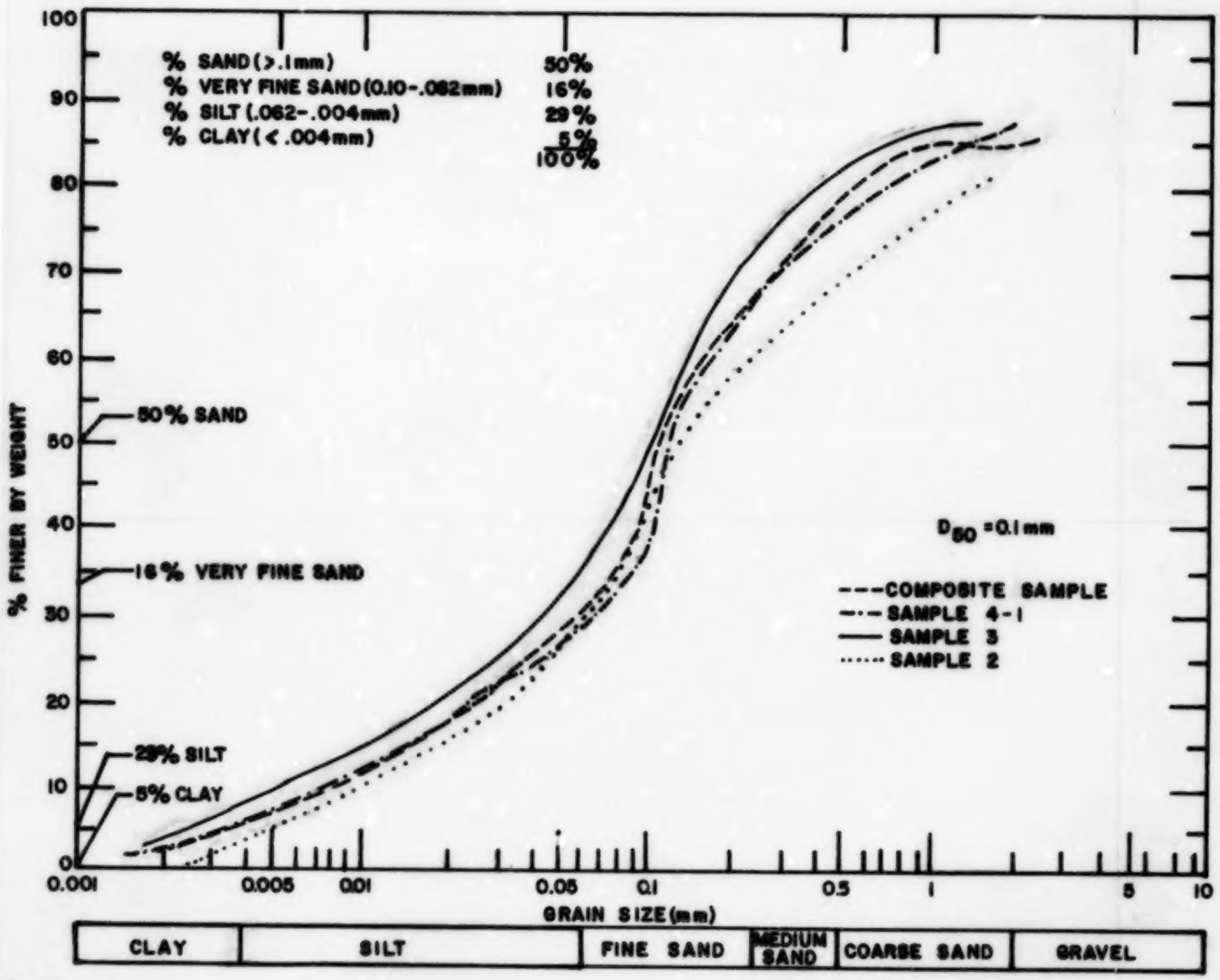


Figure 11. Predicted size distribution of eroded sediment aggregates

TABLE 3. PERCENT OF 24 HOUR RAINFALL WITH AN INTENSITY GREATER THAN 0.6 INCHES PER HOUR (1.52 CENTIMETERS/HOUR) USING AN SCS TYPE II CURVE

Frequency	Approximate Duration of Rainfall 1.52 cm/hr	Approximate % of Rainfall greater than 1.52 cm/hr
2 yrs.	3.5 hrs.	60%
5 yrs.	3.5 hrs.	65%
10 yrs.	5.0 hrs.	67%

Source: Haan & Barfield, 1978.

$$D_j = 0.0459\ R\ K_j\ CP_j\ S_j\ (\lambda_j^{M+1} - \lambda_j^{m+1}) / (72.6)^m$$

where D_j s the detachment from the segment in lbs/ft-width; R is the Universal Soil Loss Equation rainfall factor for the storm; K_j is the soil erodibility for the exposed material, CP_j is the cover practice factor for slope segment j; λ_j is the distance from the top of the slope to the bottom of the segment; m is a coefficient depending on the slope; and

$$S_j = \frac{0.43 + 30 \sin\theta + 430 \sin^2\theta}{6.613} \cos\theta$$

where θ is the angle of the slope[1]. Values for M, R, and CP_j are tabulated in Haan and Barfield (1978) and nomographs are presented for determining K_j from soil size distributions and permeability data. Detailed computations are provided in Appendix A.

Dividing the Detached Material into Bedload and Suspended Load --

The assumption was made that the detached material in the silt size range and smaller (diameter < 0.61 mm) would be transported as suspended load, and larger particles would be transported as bedload. Based on the size distribution shown in Figure 11, 65 percent of the particles would be transported as bedload and 35 percent as suspended load.

---

[1] The term Cosθ was not included in the original Universal Soil Loss Equation, but is included here to correct for the fact that steep slopes will not receive as much rainfall energy as flat slopes.

The Transport Capacity for Each Segment --

The bedload transport capacity T_{cj} is the flow exiting section j, is given by:

$$T_{cj} = r \cdot R \cdot T \cdot \lambda^2 \cdot (S')^{\beta} \cdot C_{ro} \cdot C_T$$

where T_{cj} is the transport capacity for the flow leaving the slope segment j (lbs/ft-width); r is a proportionality constant which related the product of runoff volume and peak discharge to Wischmeier's R factor; R is the return period rainfall factor from The Universal Soil Loss Equation; and C_T is the transportability reduction factor given as a function of the ratio of velocity with treatment to that of a bare fallow soil. Detailed graphs and charts for determining r, R, T, B, C_{ro}, and C_T are given in Haan and Barfield (1978), as well as Neibling and Foster (1977). The computed values of T_{cj}, for each slope segment, are shown in Appendix A.

The Final Sediment Yield --

The actual bedload sediment exiting each segment is the lesser of the transport capacity, T_{cj}, and the material available for transport. The bed material available for transport is the sum of that entering the segment and the bed material detached from the segment. The bed material exiting the segment is added to the suspended load from the segment to obtain the total sediment load exiting. Detailed calculations are given in Appendix A. The resulting sediment yield is shown in Table 4.

TABLE 4. SEDIMENT YIELD FROM THE SOURCE AREA TO THE FILTER AREA FROM A DESIGN STORM

Return Period	Sediment Yield	
Storm	Tons	kgs.
2 yrs.	40,260	18,300
5 yrs.	70,125	31,875
10 yrs.	100,000	45,455

Development of Pollutographs --

Pollutographs were developed under two assumptions: (1) that the concentrations of sediment remained constant with time, and (2) that the concentration of sediment varied with time. At the time the design computations were made, no data were available from surface mines for checking these assumptions.

Should the concentrations vary with time, a relationship has been proposed by Ward, et al (1978) which can be used to predict peak concentrations:

$$C_p = 0.0636\ (Yd/A^{0.74}\ (q_p)^{-0.394}\ t_{st}{}^{0.177}$$

where C_p is peak inflow concentration in mg/liter; Yd is the sediment yield of the storm in tons; A is the area in acres; q_p is the peak storm discharge in cfs; and t_{st} is the storm duration in hours. If the concentration is assumed to be constant, the average concentration will be given by:

$$C = \frac{Yd/2000}{62.4\forall}\ \times 10^6$$

where $\forall$ is the runoff volume in cubic feet. Detailed computations are shown in Appendix A and the results in Table 5.

TABLE 5. CALCULATED AVERAGE AND PEAK CONCENTRATIONS OF STORM RUNOFF

Return Period	Peak[2] Conc mg/liter	Avg.[1] Conc mg/liter
2 yrs.	0.610	0.089
5 yrs.	0.790	0.103
10 yrs.	0.960	0.124

[1] Concentration does not vary with time
[2] Concentration varies with time

The peak concentrations shown in Table 5 are very high, whereas the average concentrations appear to be reasonable. At the time the hydrologic design computations were made, data exited to indicate that the average concentrations can be realized and very limited data existed to indicate that the peak concentrations could be obtained.

Therefore, it was assumed that the pollutographs should be generated using the average concentrations. Thus, the resulting sediment load can be calculated from:

$$q_s = cq_w$$

where q_s is the sediment load; c is the average concentration; and q_w is the runoff hydrograph ordinates. The resulting pollutograph for a 2.5 and 10 year storm is plotted in Figure 12. Detailed computations are given in Appendix A.

The pollutographs and hydrographs for each storm frequency are used as the inputs to the grass filter model presented in Section 3.

Design Using the Kentucky Grass Filter Model

The Kentucky Grass Filter Model as given in Section 3 has been computerized in an interactive format. Inputs required for the model are given in Table 6.

TABLE 6. KENTUCKY VEGETATIVE FILTER MODEL INPUTS AND OUTPUTS

Hydrologic Inputs	Media Inputs	Outputs (Varying with Time)
Peak Inflow	Filter Length	Sediment Concentration
Sediment Concentration	Slope of Ground	Sediment Size Distribution
Sediment Size Distribution	Media Spacing & Size	Fraction of Media Inundated
	Media Height	
	Filter Width	
	Infiltration Rate	
	Manning's Roughness	

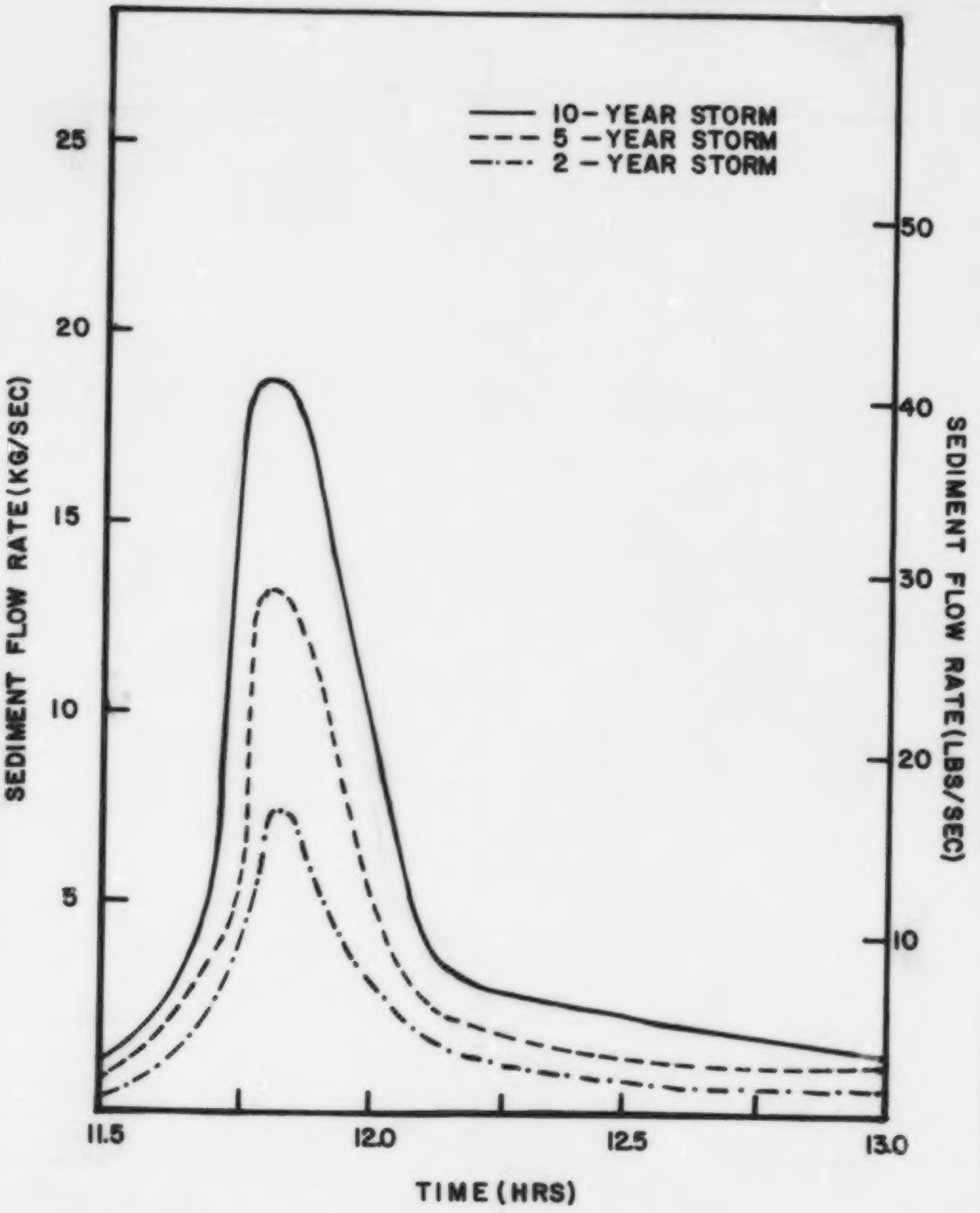


Figure 12. Predicted runoff pollutographs

A complete listing is given in Hayes, et al (1981), as well as graphical solution procedures. At the time the hydrologic design computations were made, the component, which accounted for the effects of infiltration on the sediment mass balance, had not bee developed. The results, therefore, should be conservative.

Model Sensitivity Analysis --

A sensitivity analysis was conducted, as part of the hydrologic design, to determine the sensitivity of the model to the input parameters of filter length, width, Manning's n, media spacing, and media size. Standard values were input into the model as a reference, and one by one, parameters were allowed to vary over a range one might expect to encounter in the field (referred to as a single parameter sensitivity analysis - Table 7).

TABLE 7. VALUES USED FOR SENSITIVITY ANALYSIS OF KENTUCKY GRASS FILTER DESIGN MODEL

Parameters	Standard Value	Ranges	
Grass Spacing (cm)	1.6	1.0 -	2.0
Grass Diameter (cm)	0.1	0.08 -	0.13
Manning's n	0.012	0.009 -	0.016
Max. Deposition (cm)	0.75	0.300 -	1.500
Media Height (cm)	12.0	8.0 -	16.0
Time Increments (secs.)	20.0	5.0 -	60.0
Slope (%)	10.0	3.0 -	25.0
Slope Length (meters)	41.0	10.0 -	100.0
Slope Width (feet)	21.0	20.0 -	140.0
Infiltration Rate 1/	-	-	-

1/ At the time of the hydrologic design, procedures had not been developed to account for the effects of infiltration on the sediment mass balance.

Runoff and sediment pollutographs from the ten, five, and two year storm were input into the model, and outflow pollutographs from the grass filter were predicted for each set of conditions. Plots showing how the peak outflow sediment concentration varied with each input parameter are provided in Appendix B. From a visual inspection of the plots the parameters which are most important are slope, filter width, and filter length. A reasonable estimate is sufficient for the other input parameters.

Selection of a Filter Design

In the selection of a final design, the following criteria were considered:

(1) Minimize earth movement,
(2) Keep slope as close as possible to the natural slope of the ground,
(3) Allow for monitoring of inflow and outflow from the filter,
(4) Vegetative density and height must be such that they can be rapidly obtained, and
(5) Maximum possible trapping efficiency for the site selected.

Based on these criteria, a vegetative filter was selected with the characteristics shown in Table 8.

TABLE 8. DESIGN VEGETATIVE FILTER CHARACTERISTICS

Slope	17%
Length	41.0 meters
Width	21.0 meters
Spacing	1.6 cm
Type vegetation	To be determined
Hydraulic parameters for predicting model	Kentucky 31 Fescue
Grass diameter	.1 cm
Manning's n	.012
Media height	12.0 cm

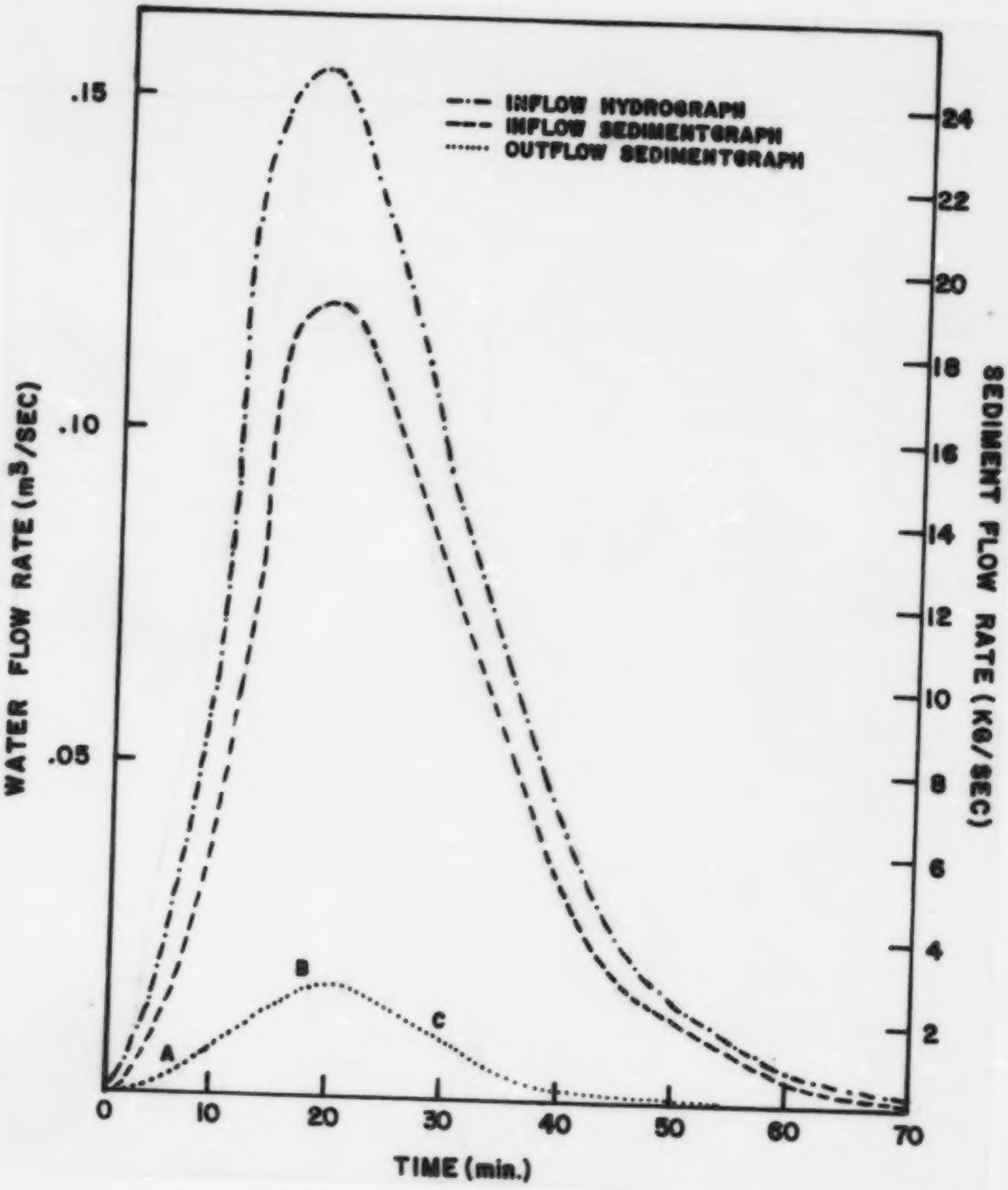


Figure 13. Predicted hydrograph and pollutographs for the design filter with a 10 year storm

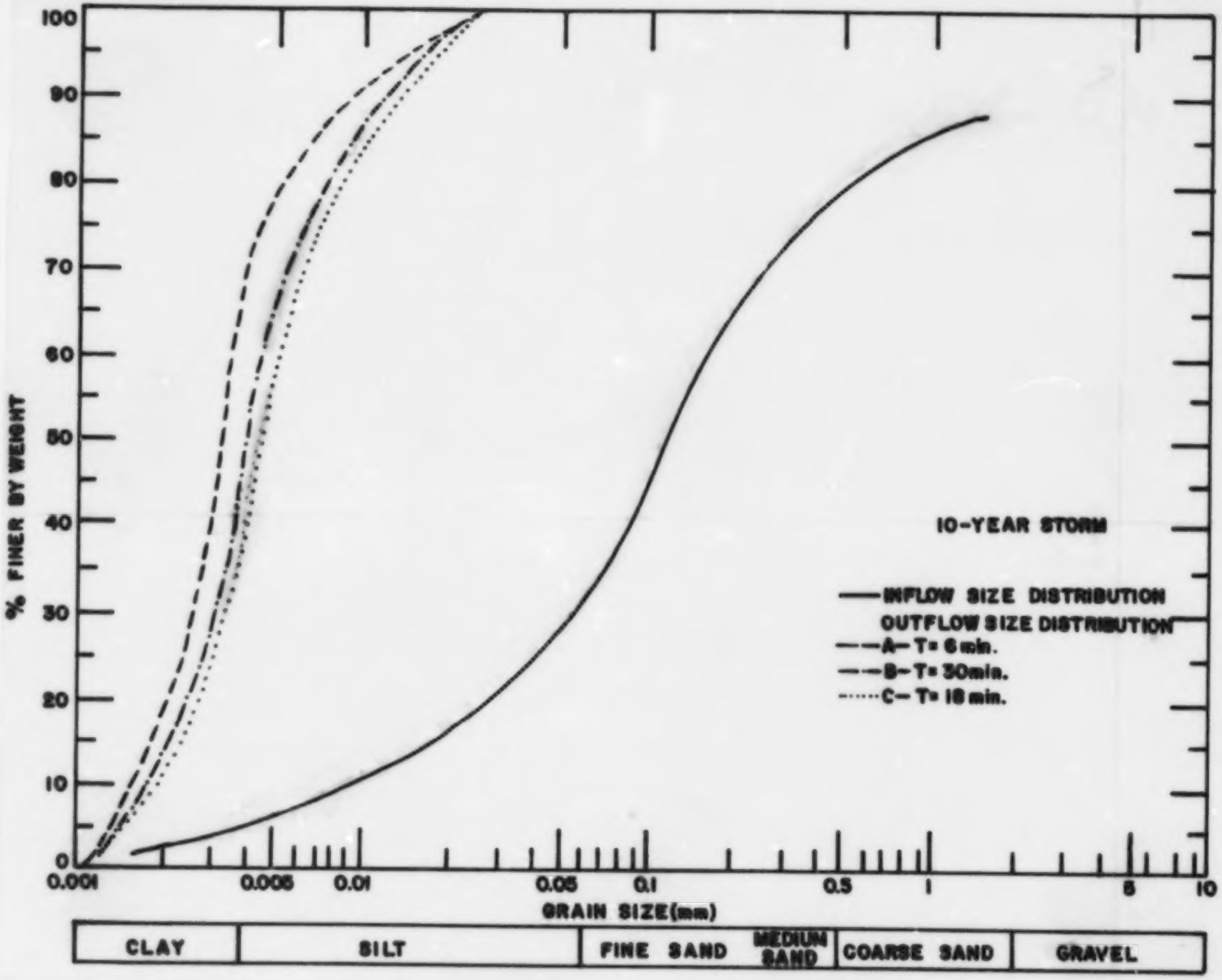


Figure 14. Predicted inflow and outflow sediment

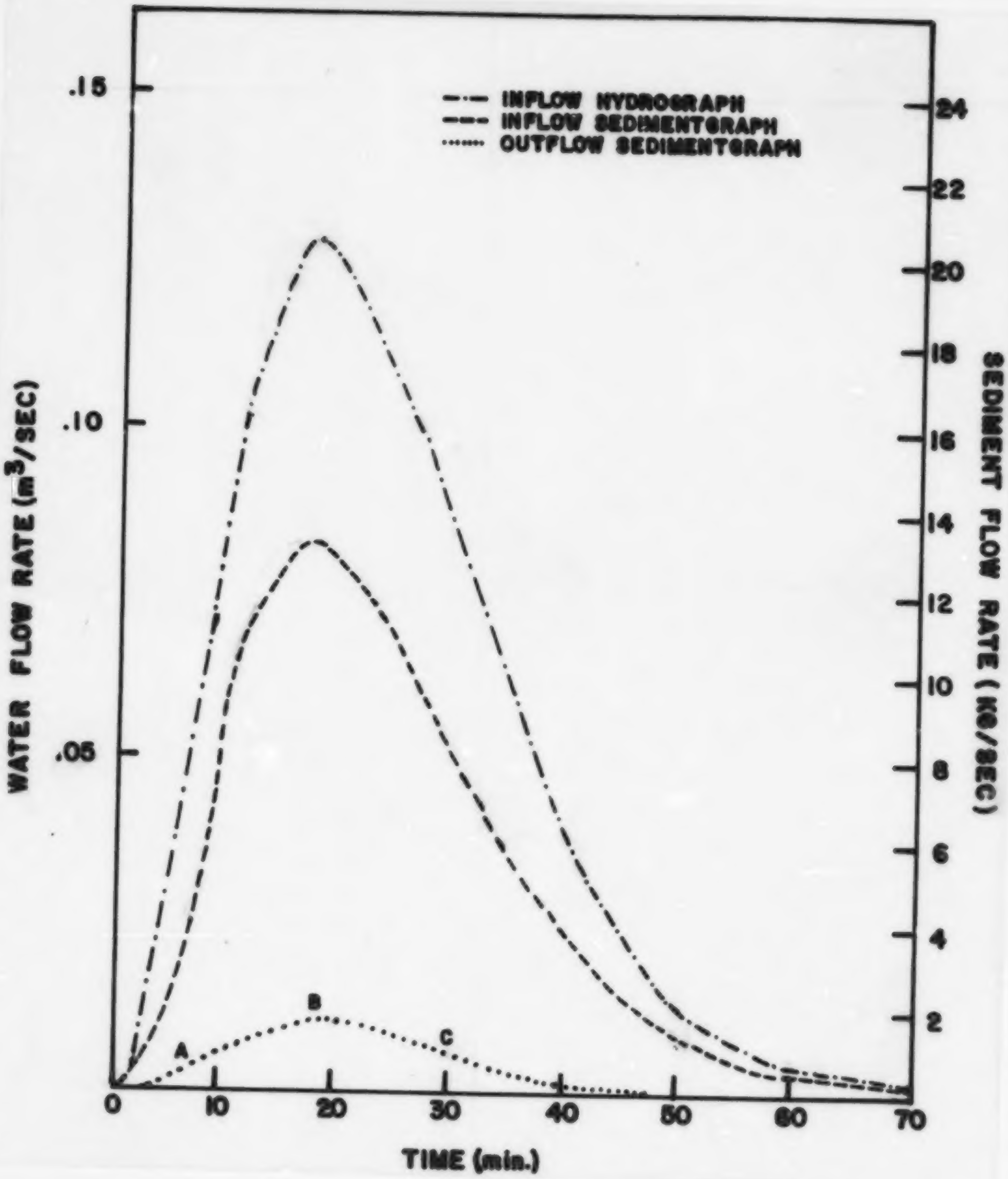


Figure 15. Predicted hydrograph and pollutographs for the design filter with a 5 year storm

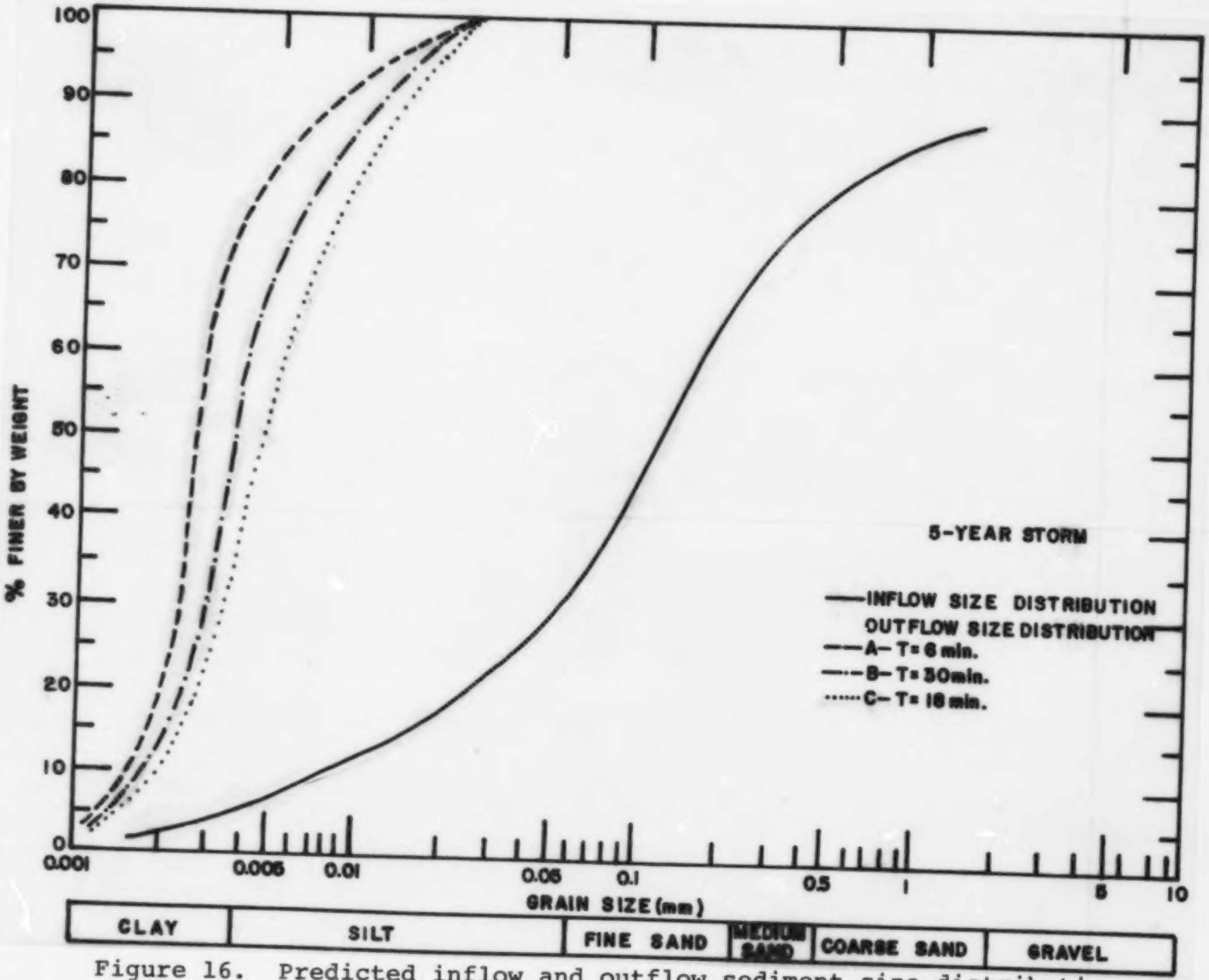


Figure 16. Predicted inflow and outflow sediment size distributions for the design filter using a 5 year storm

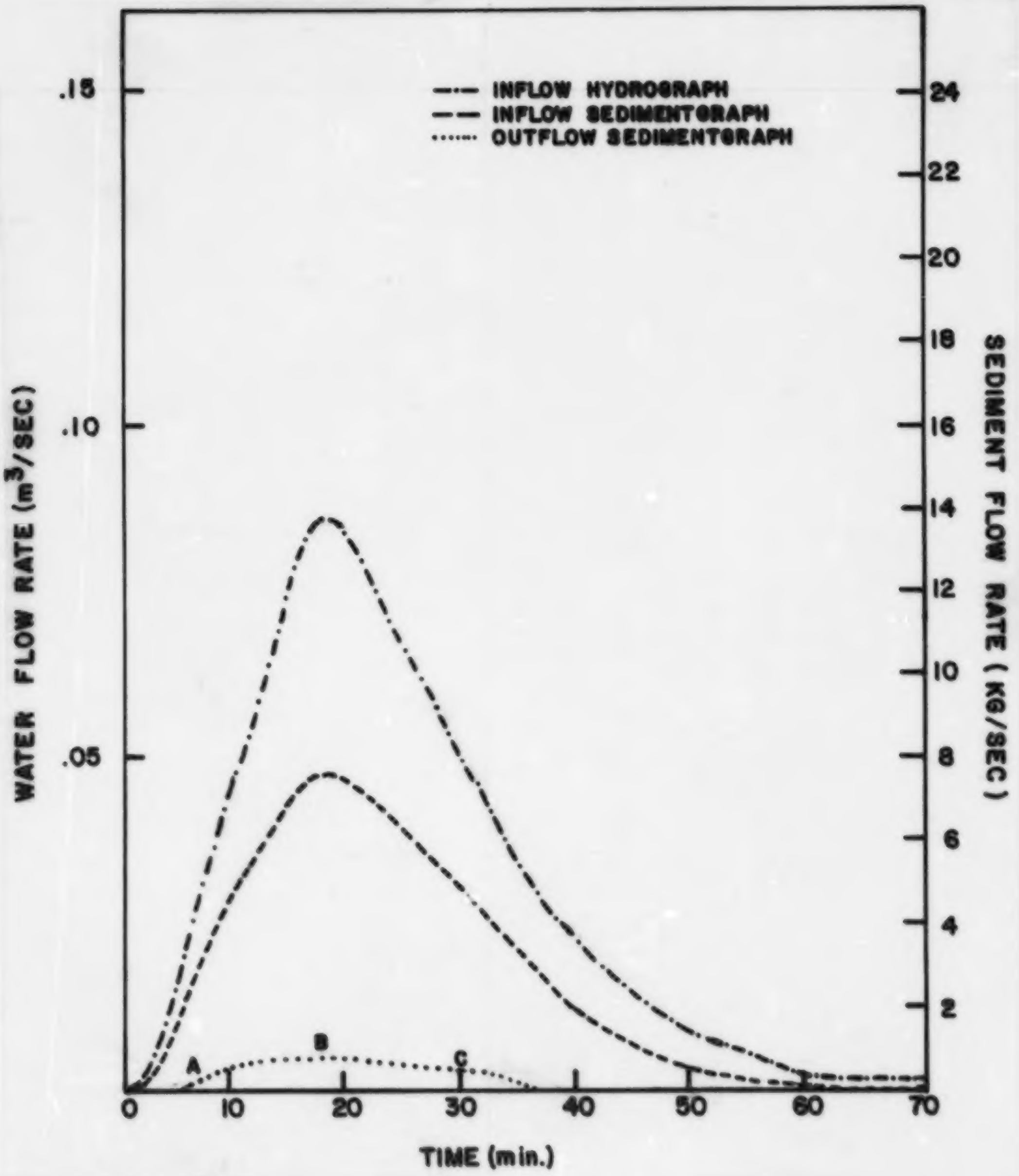


Figure 17. Predicted hydrograph and pollutographs for the design filter with a 2 year storm

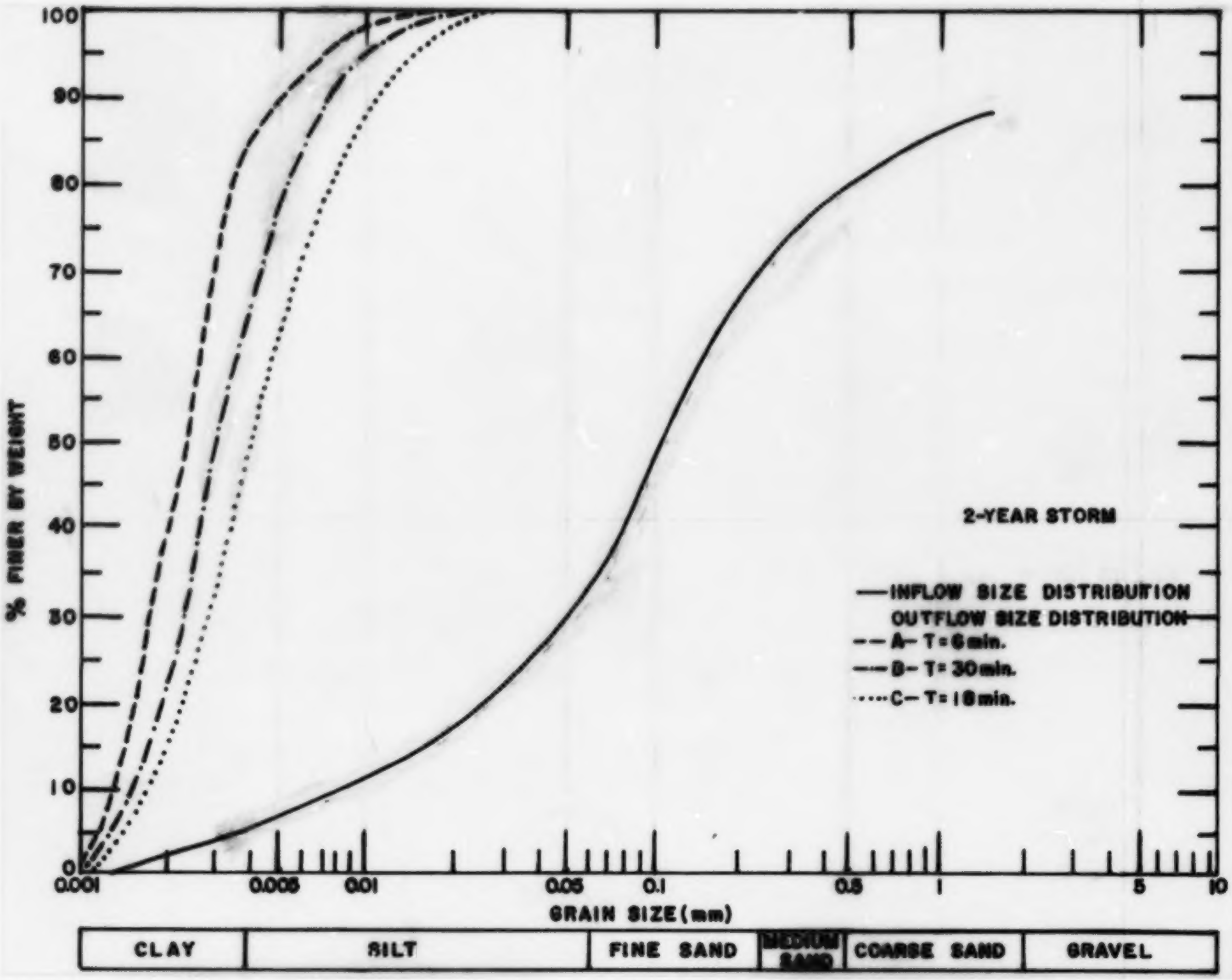


Figure 18. Predicted inflow and outflow sediment size distributions for the design filter using a 2 year storm

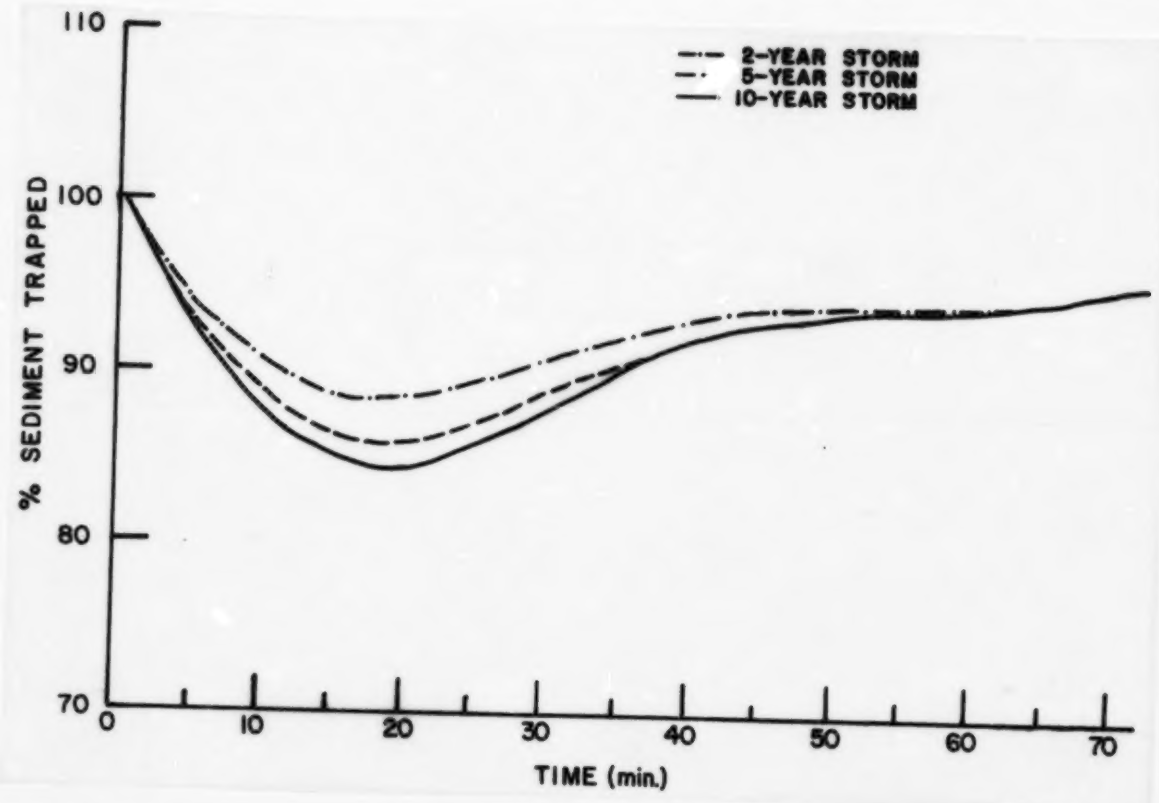


Figure 19. Predicted instantaneous trapping percentages for the design filter with a 2, 5 and 10 year storm

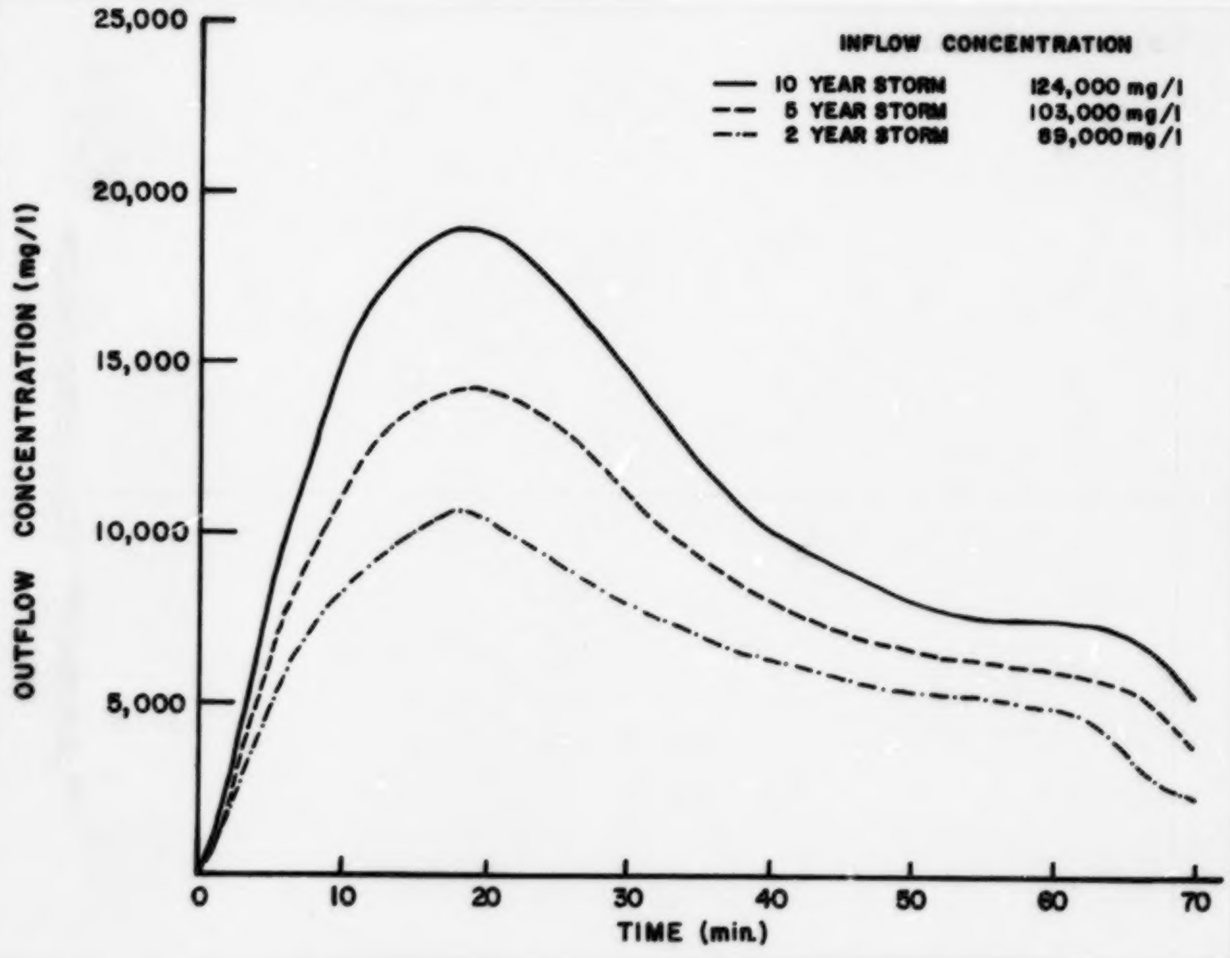


Figure 20. Predicted outflow concentrations for the design filter for a 2, 5 and 10 year storm

Design Sediment Predictions --

Predicted sediment inflows, outflows, and size distributions are shown in Figures 13 through 20 for the design selected. The predictions indicate that vegetation will drastically reduce the sediment load for all of the return period storms considered. All of the sand and the larger silt size particles are trapped by the vegetative filter.

When the outflow sediment graphs are converted to concentrations, Figure 19, the resulting concentrations appear to be quite large. However, when considered in light of the inflow concentrations, the fraction of sediment trapped is obviously quite high. All of the instantaneous percentages are greater than 85 percent as shown in Figure 19.

VEGETATIVE DESIGN

As is the case with almost all environmental activities, planning is the key to the success of vegetative establishment. Four major planning phases should be investigated before beginning any field activities. These phases include:

- preliminary site and soil survey,
- vegetative species selection,
- fertilization program,
- seeding plan

Preliminary Site and Soil Survey

The first item for consideration was the soil reconnaissance. Before any work on the site began, the soils were thoroughly tested for a minimum of buffer pH, phosphorus and potassium. Composite soil samples were taken from both the top and subsoils to detect any toxic or acidic problems that might be present.

In addition to soil fertility information, the quantities of soil available become very important when selecting vegetation. The topsoil on the site was removed, stockpiled, and then replaced, with the total depth ranging from 10.2 to 15.3 centimeters. This determination limited the types of vegetation which could be utilized, due to the acid conditions in the subsoil. Only by careful evaluation of fertility levels and soil characteristics can unsuccessful vegetative stands be averted. Further knowledge of the area can be gained by noting the existing vegetation and how well it is adapted to the site, and whether the plant species present are native or introduced.

Vegetation Species Selection

The second phase in planning for vegetative establishment is the actual selection of vegetative species to be seeded in the filter area. The following discussion of selecting a grass for this very specialized use is directed toward the surface mining areas of the Eastern coal fields, where the vegetative filter test site is located. This section is not to be confused, however, with general revegetation practices, although some are evident in the procedures utilized. The selection of suitable vegetal media revolves around the evaluation of ten major factors:

- Soil condition and depth
- Soil chemical analysis
- Characteristics of sediment to be trapped in the filter
- Specific establishment procedures
- Maintenance requirements
- Duration of filter site use
- Selection of vegetation adapted to area climatic conditions
- Current on-site vegetative species
- Major stresses encountered by the vegetation
- Physical site limitations

For the purposes of this report, discussion of these factors will be directed to the specific needs of the study area.

Soil Condition and Depth --

Different species of vegetation require different types and depths of soil rooting medium. For example, a legume such as alfalfa develops a taproot which penetrates deep into the soil profile, while bluegrass, on the other hand, develops a very shallow and fibrous root system. The vegetation should be selected to meet the soil limitations found on the site. In the case of the study area, the subsoils are very acid and only 12.7 centimeters of topsoil were available for use as a growth medium. A root growing into this very acid subsoil would definitely limit the plant's uptake of nutrients and growth, unless a very high acid resistance was exhibited by the plant. The main limiting factor in this category, in view of the above considerations, is the rooting depth of the plant species.

Soil Chemical Analysis --

Information gathered during the initial soil testing program is utilized to match the soil fertility to the nutrient requirements of the plant. As an example, some plants can tolerate very acid conditions and continue almost normal growth when no other limiting factors are present. If the study area is plagued by acid conditions and very low phosphorus levels are indicated, this should be taken into consideration when selecting vegetation.

Characteristics of Sediment to be Trapped --

Surface testing of the material to be trapped by the filter should also be considered. Since eroded material, when diverted into the filter zone, would be trapped and deposited on the soil surface surrounding the vegetation. Characteristics of this trapped material could dramatically effect the survival of the plants. The acid conditions on the study site prompted the application of 1200 pounds (544 Kilograms) of additional agricultural lime to the top 3.05 meters of the filter, to counteract the high acid concentrations expected in the inflow. Chemical testing for pH should have given good indictions of problems that might be encountered from inflow containing high concentrations of toxic micro-nutrients.

Specific Establishment Procedures --

When considering a vegetative species for planting, evaluate how the planting would be accomplished and specifically what equipment would be used. In most situations, the size of the area involved would determine the equipment that could be used efficiently. Of course, equipment already available could be adapted for use in seed-bed preparation and seeding. This takes into consideration the fact that the seed should be covered for good germination and quick erosion control.

Maintenance Requirements --

Different grass species may require totally different levels of management. Some species require high fertilization levels and disease control precautions. Low maintenance was a key factor in the selection of vegetation for this project. By placing the vegetation under abnormal stress conditions, some maintenance will inevitably be required. Consequently, it is desirable to select a species which may require very little maintenance under normal conditions.

Duration of Filter Site for Use --

In the development of a mine plan, estimations are based on the amount of time an area will be disturbed by the mining process. The same type of evaluation should be made in the design of the vegetative filter zone. Some vegetative species are characterized by an annual growth habit and some are perennial; the choice of which type to use being dependent on criteria set on deviation of use and site conditions. The monitoring period established for this study was one year. The growth cycle would need to be perennial in order to perpetuate the vegetation through the life of the project. The post-mining land use of the area also merited consideration so that double handling of the soil material would not be necessary.

Selection of Vegetation Adapted to Area Climatic Conditions --

In the Southeastern Kentucky study area, several species of vegetation are well adapted for normal growth. In other areas of the country, a completely different set of vegetation species may be required for good adaptions. Both cool and warm-season grasses are found in the Eastern coal fields, but the predominant species are cool-season. The growth habit of the cool-season species denotes high growth activity between the 10 and 24 degrees centigrade temperature range. Optimum growth period for Kentucky cool-season grasses are in the spring and fall of the year. This growth period matches well with the times of high rainfall and the runoff in the project area. Depending on the individual case, the warm-season species might be more applicable to other areas of the country.

Existing On-Site Vegetative Species --

Observation of existing plant species under natural conditions may indicate potential site problems. The most evident visual assessment, which is easily distinguished, is an acid toxic condition in the soil. Stunted vegetation, or in some cases, an absence of existing vegetation, can indicate problems with pH or toxic elements.

Major Stresses Encountered by the Vegetation --

Normal field conditions introduce the natural forces of rainfall and drought conditions, but these stresses are greatly amplified when the vegetation is utilized as a sediment control device. Flowing water creates problems by not allowing the vegetation an upright growth habit. Grass species with weak or low-growing stems can lay over under the forces of flowing water and create a grass waterway. This is detrimental, since erect growth is essential for the effective trapping of eroded sediment. Physiological stresses, such as wet or dry conditions, are also placed on the plant. The plant species selected for use must exhibit a tolerance to the above mentioned stress conditions.

Physical Site Limitations --

Steep slopes can create varied problems in vegetation establishment, one of which may be averted by choosing a plant species with a quick establishment growth habit. The faster a species establishes itself, the less the chance of erosion or loss of seed. At least one species in the seeding mixture should germinate and grow very quickly.

Plant Descriptions --

Based on the examination of the ten factors affecting the vegetative selection, two vegetative species were chosen for seeding in the study area. The following descriptions reflect the objectives of the search for the proper vegetation.

Tall Fescue - (Festuca Arundinacea) -- Tall fescue is a deep-rooted, long-lived perennial whose growth habit is typically a bunch grass, although some short underground stems do occur. The roots are tough and coarse and contribute to good sod production under proper seeding conditions.

This variety of fescue is adapted to a wide range of climatic conditions and is grown from Florida to Canada. Due to its cool-season growth habit, the best adaptation occurs in the central and northern transition regions of its range (Figure 21). However, tall fescue is the only cool-season grass which will persist through the hot summers and cool winters, year after year, in the southeast.

Tall fescue is very tolerant of poor drainage, particularly in the winter months. It is capable of thriving in many of the poorly drained areas in the U.S. and Europe. This plant's tolerance to poor drainage is exceeded only by its drought tolerance. A deep, fibrous rooting system enables this fescue to withstand lengthy periods of very dry weather.

Soil pH ranges best suited to this species are from 5.5 to 6.5 although pH's from 4.7 to 8.5 can be tolerated. The tolerance of tall fescue to saline and alkaline soil conditions is better than most other cool-season turf grasses.

Perennial Ryegrass (Lolium perenne) -- The ryegrasses are considered to have a bunch-type growth habit, with no record of a creeping nature. Perennial ryegrass is commonly used in pasture mixtures and in a high quality forage. This species is not long-lived and persists for only three (3) to four (4) years before thinning begins.

Ryegrass is grown west of the Sierra Nevada and Cascade Ranges and in the southern humid regions of the U.S. Its use also extends up the Atlantic Coast (Figure 22). Ryegrass is less winter hardy than certain other forages such as Timothy and Orchardgrass.

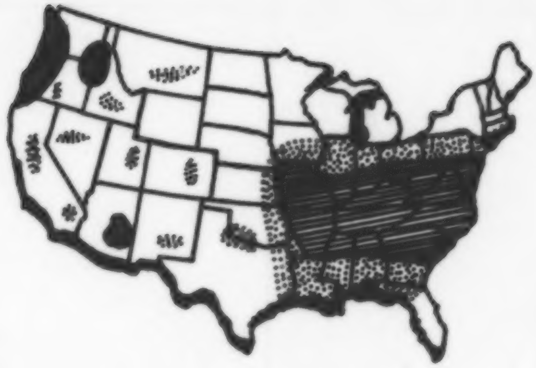


Figure 21. Tall fescue producing areas of the U.S. (37)

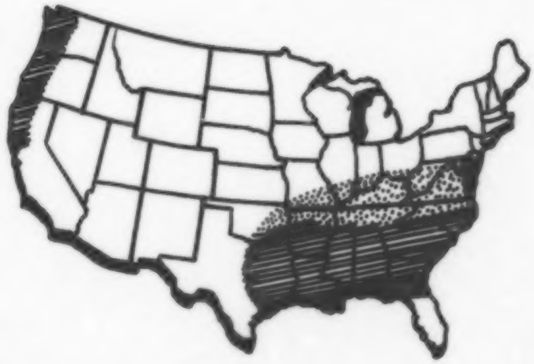


Figure 22. Ryegrass producing areas of the U.S. (37)

The ryegrasses are well-adapted to most soil types although they do not respond well to low fertility. Best growth occurs on neutral to slightly acidic soils of medium to high fertility. Tolerance to wet conditions is good, as long as there is adequate surface drainage.

These two grass species meet the criteria for revegetative selection, as previously outlined in both their physical and chemical characteristics. In addition to the parameters for selection, one other important factor was taken into consideration. The computer model developed at the University of Kentucky had for one of its inputs the diameter of the vegetative species seeded in the filter. Since one of the subordinate objectives of the study was to compare actual field data with information predicted by the model, the species chosen are of approximately the same diameter at maturity. By design, this would reduce the inputs into the computer program and make the validation of the model more reliable.

Fertilization Program

The third step in the establishment of a vegetative cover is the development of a fertilization program. The recommendations discussed in this section are based on information available in the University of Kentucky Extension Publication, AGR 40, which describes the fertilization of mine spoils.

Before a final decision was made on a fertilization plan, the optimum conditions for growth of the chosen vegetative species were considered. Tall fescue can tolerate high or low levels of fertilization as well as acid conditions. Perennial Ryegrass is more adapted to high levels of fertilization for optimum growth. The following discussion of relative amounts of nitrogen, phosphorus, and potassium nutrients are tailored to soil requirements and optimum growth of the plant species selection.

Soil samples collected during the preliminary site and soil survey were utilized to calculate the amounts of fertilizer needed for vegetative establishment. The results of these tests are shown in Table 9.

Based on the soil test results, the following recommendations were made on lime, nitrogen, phosphorus and potassium for use as soil amendments.

TABLE 9. SOIL TEST RESULTS

	Topsoil	Subsoil
pH (water)	5.6	5.2
pH (buffer)	6.5	5.9
Phosphorus	1	4
Potassium	156	121

Lime --

The test results show a buffer pH reading of 6.5 and the corresponding lime rate from AGR 40 is three tons/acre. Due to the possible stress of acid materials washing into the filter from the outslopes, the lime rate was increased to five tons/acre. This increased rate would buffer the soil against acid drainage and further amend soil pH to acceptable levels for vegetative growth. Argicultural lime was applied in pelleted form. The five ton requirement stated above translates to 3700 pounds (1678 Kilograms) of lime for the filter area.

Nitrogen --

Nitrogen amounts utilized for initial vegetative establishment are typical of the new seeding practices of any grass species. Thirty pounds (13 Kilograms) of actual nitrogen per acre would be applied at the time of seeding. This translates to 33 pounds (15 Kilograms) of ammonium nitrate for the filter area. When the vegetation reached a height of four to five centimeters, an additional five to ten pounds (2 to 4 Kilograms) of nitrogen would be added to optimize growth. Maintenance fertilization with nitrogen through the course of the project would be based on the characteristics of the grass species.

Phosphorus --

The levels of phosphorus in the soil at the time of seeding can be one of the most limiting factors to germination and growth. Phosphorus levels in the area were very low and could cause various problems with establishment of the grasses. One-hundred fifty pounds (68 Kilograms) of P_2O_5/acre would be required to raise the phosphorus level to an acceptable point. This translates into 55 pounds (15 Kilograms) of a 0-0-60 potassium fertilizer.

Seeding Plan

Seeding rates were chosen to meet both the design criteria for sediment trapping and the overall requirements of the study. In common terms, the seeding rates used are approximately half those used for seeding a lawn. These rates are used for generating thick stands of dense vegetative cover.

From the preliminary design calculations, a grass spacing of 1.6 centimeters was considered necessary for the filter area. This spacing interval met the requirements of the flow introduced into the filter area for monitoring.

In order to achieve the required density, 75 pounds (34 Kilograms) of tall fescue seed and 30 pounds (14 Kilograms) of perennial rye were seeded on a per acre basis. Reasons governing the use of the two grasses were covered under the vegetative selection section. Rates of seeding were governed by the density requirement of the grass as outlined in the design criteria.

MONITORING SYSTEM DESIGN

The original task description of the project outlined a hand sampling program to monitor inlet and outlet sediment concentrations. The monitoring program was altered considerably when the University of Kentucky, Department of Agricultural Engineering agreed to cooperate in the project. The University's interest in the project stemmed from their previous work in vegetative filters. During earlier vegetative filter design work, the computer model discussed in this report was developed from laboratory data. This project allowed the university an opportunity to test the validity of the model in the field. The data required by the university was more extensive and thus required a more sophisticated monitoring system. The monitoring equipment discussed below was used in the study primarily because of its availability at the start of the project.

The monitoring system revolved around several major components which were combined to provide a complete system. These components include those listed in Table 10.

The H-Flumes were designed and built for the purpose of handling a ten-year storm event. Designing the flumes for a two-year event was considered, but discounted on the premise that should a large event occur, it would not be effectivley monitored. On the other hand, if the upper limit

TABLE 10. MONITORING INSTRUMENTATION

Parameter	Instrument	Manufacturer
Water flow rate	H-Flume and water stage recorder	Stevens (Model 71 recorder)
Sediment Concentration	Automatic pumping	Isco (Model 1680)
Rainfall	Weight type rain-gauge	Weathermeasure

were set on a ten year event, any storm of a low return period might not be detected. The 1.5 foot H-Flume was selected because it better fit the flow characteristics expected on the site. The flumes were constructed from sixteen gauge sheet metal by the University of Kentucky.

Following construction, the H-Flumes were calibrated at the University of Kentucky engineering water laboratories. The methods of calibration were:

- high flow - flow rate measured by calibrated venturi meter, and
- low flow - flow rate measured by dye tracer techniques.

(calibration curves are shown in Figure 23).

In addition to the flumes, a metal flow divider was also designed and constructed. The divider was designed for location directly below the inlet flume. As the flow of water passed through the flume, it dropped into a splash box, and then into the flow divider network. The metal flow divider consisted of a row of metal plates positioned to separate the total discharge into fourteen equal flows. Attached to the metal plates were the two-by-four dividers which would distribute the flow equally across the width of the filter area. Design details of the inlet flume installation, metal flow divider, outlet flume installation and H-Flume plans are shown in Figures 24 and 25.

The Stevens water stage recorder, with chart drive, operated from a float activated by a stilling well on the flume. The details regarding installation of this equipment are discussed in the water monitoring installation section.

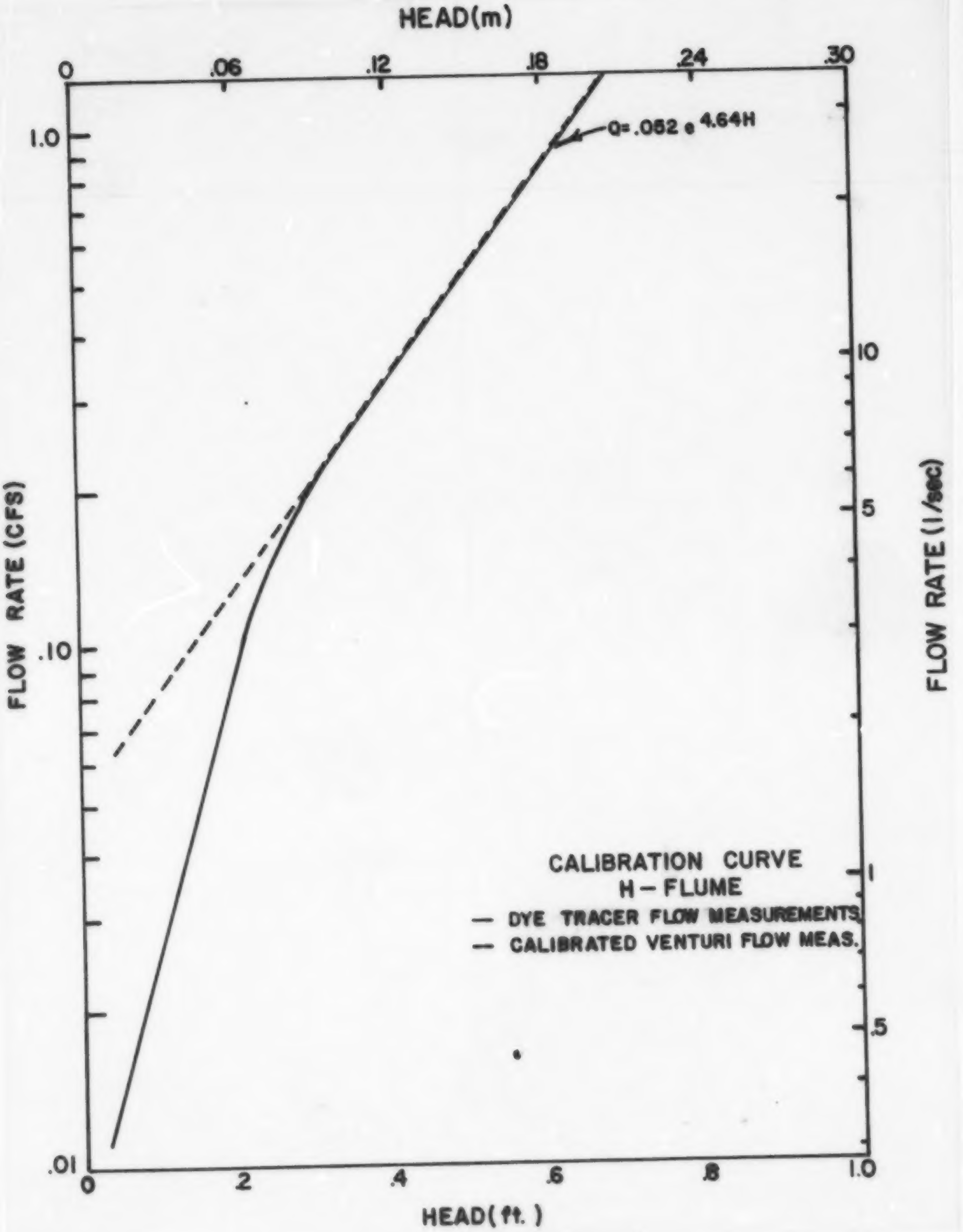


Figure 23. Calibration curves for the H-Flumes

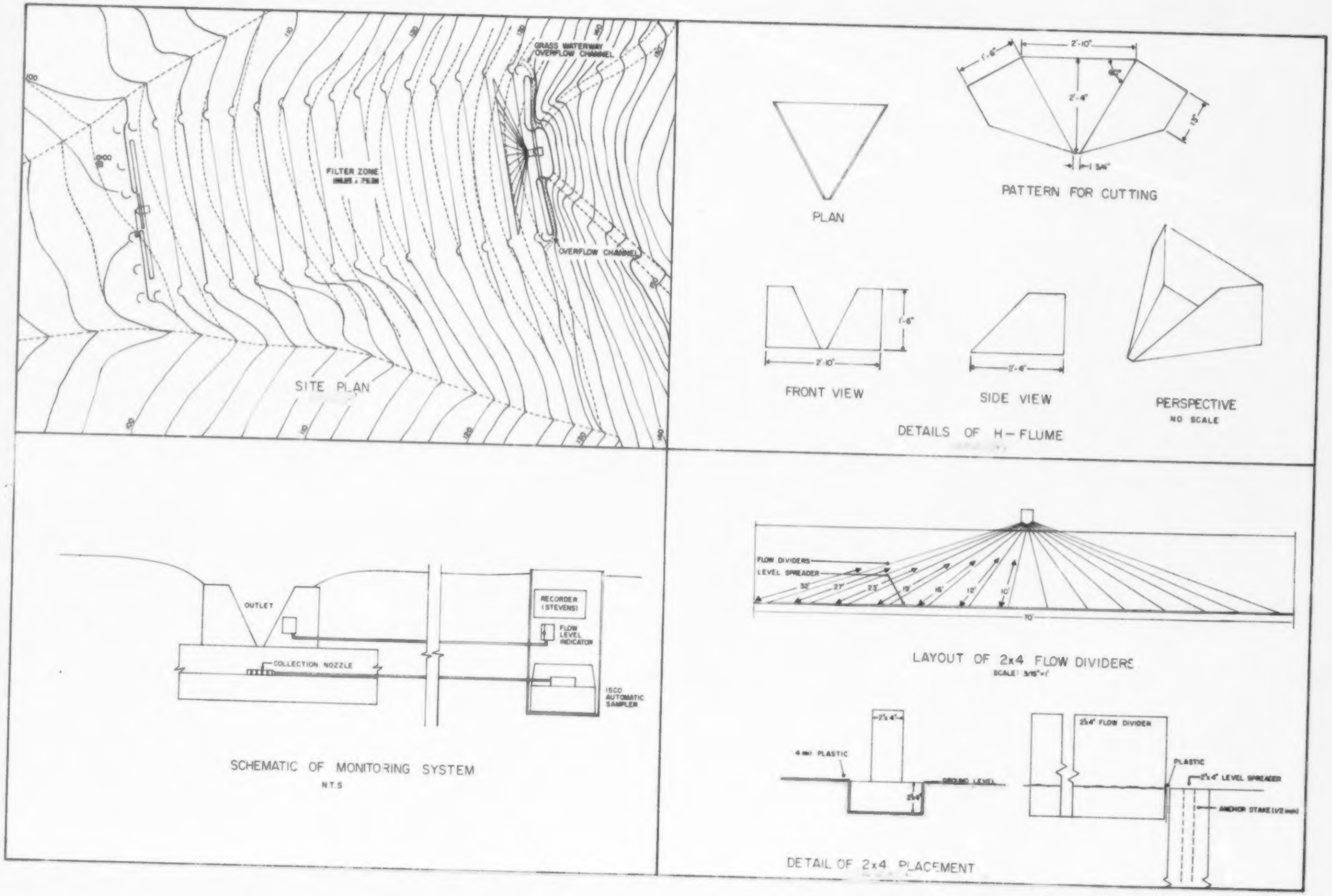

GRASS WATERWAY OVERFLOW CHANNEL
FILTER ZONE
OVERFLOW CHANNEL
SITE PLAN
PLAN
PATTERN FOR CUTTING
2'-10"
2'-4"
1'-6"
1 3/4"
FRONT VIEW
SIDE VIEW
PERSPECTIVE
NO SCALE
DETAILS OF H-FLUME
OUTLET
COLLECTION NOZZLE
RECORDER (STEVENS)
FLOW LEVEL INDICATOR
ISCO AUTOMATIC SAMPLER
SCHEMATIC OF MONITORING SYSTEM
N.T.S
FLOW DIVIDERS
LEVEL SPREADER
70'
LAYOUT OF 2x4 FLOW DIVIDERS
SCALE: 3/16"=1'
4 mil PLASTIC
GROUND LEVEL
2x4" FLOW DIVIDER
PLASTIC
2x4" LEVEL SPREADER
ANCHOR STAKE
DETAIL OF 2x4 PLACEMENT

Figure 24. Design drawings for site plan, monitoring system, H-Flume, and flow divider

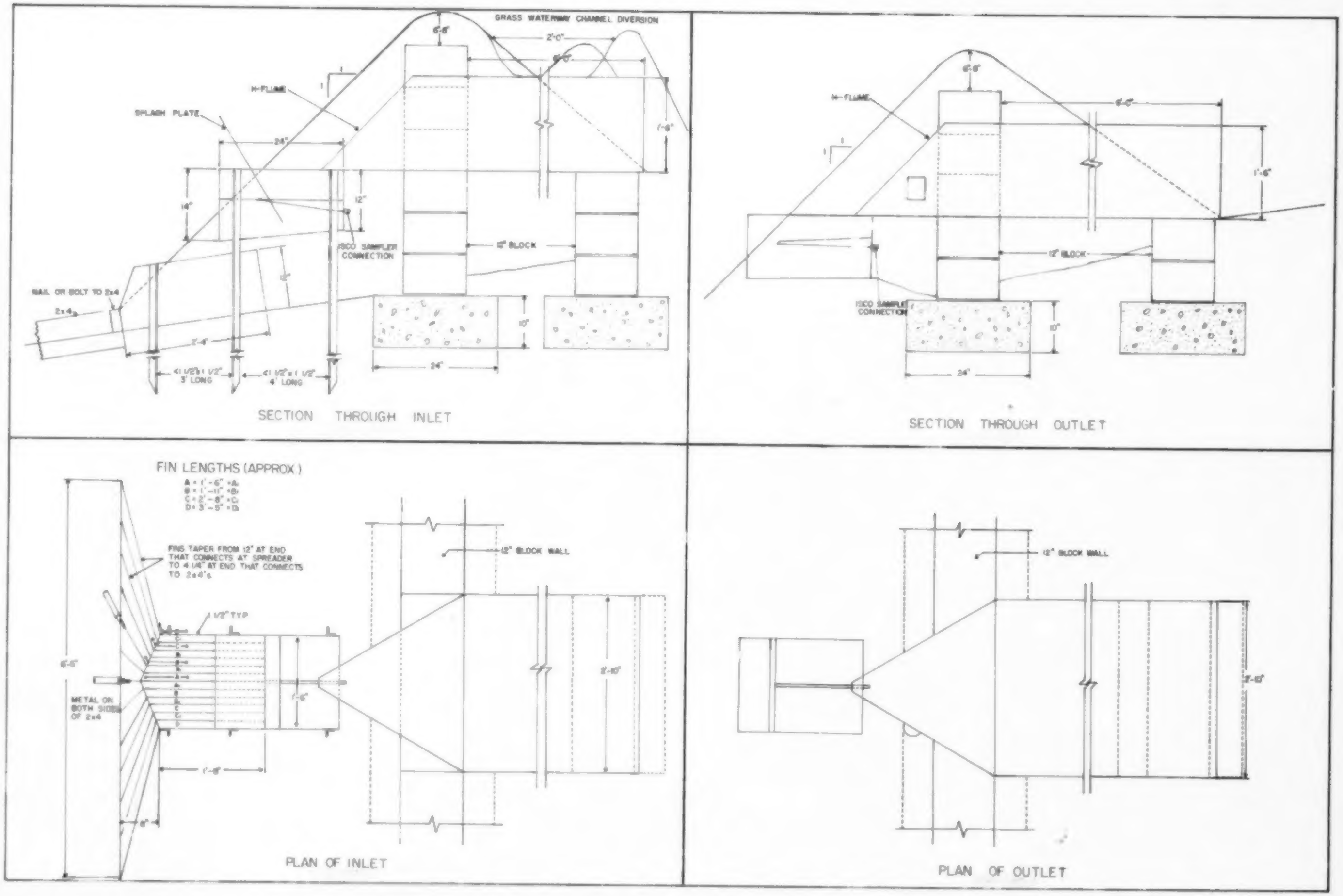

GRASS WATERWAY CHANNEL DIVERSION
6'-8"
2'-0"
6'-0"
1'-6"
H-FLUME
SPLASH PLATE
24"
14"
12"
ISCO SAMPLER CONNECTION
12" BLOCK
NAIL OR BOLT TO 2x4
2x4
2'-4"
<1 1/2"x 1 1/2" 3' LONG
<1 1/2"x 1 1/2" 4' LONG
10"
24"
SECTION THROUGH INLET
H-FLUME
6'-8"
6'-0"
1'-6"
12" BLOCK
ISCO SAMPLER CONNECTION
10"
24"
SECTION THROUGH OUTLET
FIN LENGTHS (APPROX.)
A = 1'-6" = A₁
B = 1'-11" = B₁
C = 2'-8" = C₁
D = 3'-5" = D₁
FINS TAPER FROM 12" AT END THAT CONNECTS AT SPREADER TO 4 1/4" AT END THAT CONNECTS TO 2x4's
1/2" TYP
6'-6"
METAL ON BOTH SIDES OF 2x4
1'-6"
1'-8"
6"
12" BLOCK WALL
2'-10"
PLAN OF INLET
12" BLOCK WALL
2'-10"
PLAN OF OUTLET

Figure 25. Design drawings for inlet and outlet flume implacements

The Isco pumping sampler was selected because it could be set on either a time mode or a flow mode, depending on the application desired. Sampling under this system could take place automatically -- initiated by flow, and the samples could be collected later by project personnel. The thirty centimeter raingauge was equipped with a clock drive unit set for monthly recording.

The equipment was totally self-sufficient; battery power was used by all instruments. All instruments were housed in corrugated steel containers to avoid theft and damage by weather.

Instrumentation such as that described above was utilized to meet the data collection and research needs of the project. Actual field use of a vegetative filter by the mining industry would not require the use of an extensive monitoring system such as the one described.

SECTION 5

INSTALLATION OF VEGETATIVE FILTER

General topics to be discussed in this section include: site alterations and soil handling, vegetative establishment, water monitoring system installation and costs for filter installation. The overall goal of the techniques utilized in the filter construction was to simulate actual mining techniques for soil handling. Site specific conditions were carefully considered and design criteria established before work began on actual installation of the filter area.

SITE ALTERATIONS AND SOIL HANDLING

The initial phase of site alterations consisted of setting grade stakes for use by the bulldozer operator as guidelines. These stakes were placed to leave an area 41.0 meters in length, 21.0 meters in width on a seventeen (17) percent slope. The rationale describing the design criteria behind the seventeen (17) percent slope was discussed in detail under the design considerations section. In order to achieve the desired slope, soil had to be removed from the rise and spread to form the level area for the filter. The depth of removal would exceed the 12.7 to 15.2 centimeters topsoil depth and extend into the subsoil. Since the subsoils in this area of Kentucky are highly acid (pH 2.0 to 4.0), the topsoil would be removed (Figure 26) and redeposited after subsoil leveling. The topsoil material was stockpiled beside the area for redistribution after grading.

Rough grading of the subsoil material took place between the four grade stakes placed on the corners of the rectangular filter area as reference marks (Figure 27). Accuracy needed for purposes of the study demanded 3.1 centimeters level across the subsoil surface. If this level were not maintained, channelizing could take place and erosion would adversely affect the results of the field tests.

As previously discussed, the subsoil has an inherent fault which could greatly inhibit plant growth. This deficiency is a very low pH, which can severely limit nutrient uptake in plants. To the best of our knowledge, the technique utilized in this study to correct the problem had never been attempted before this experiment. The lime requirement

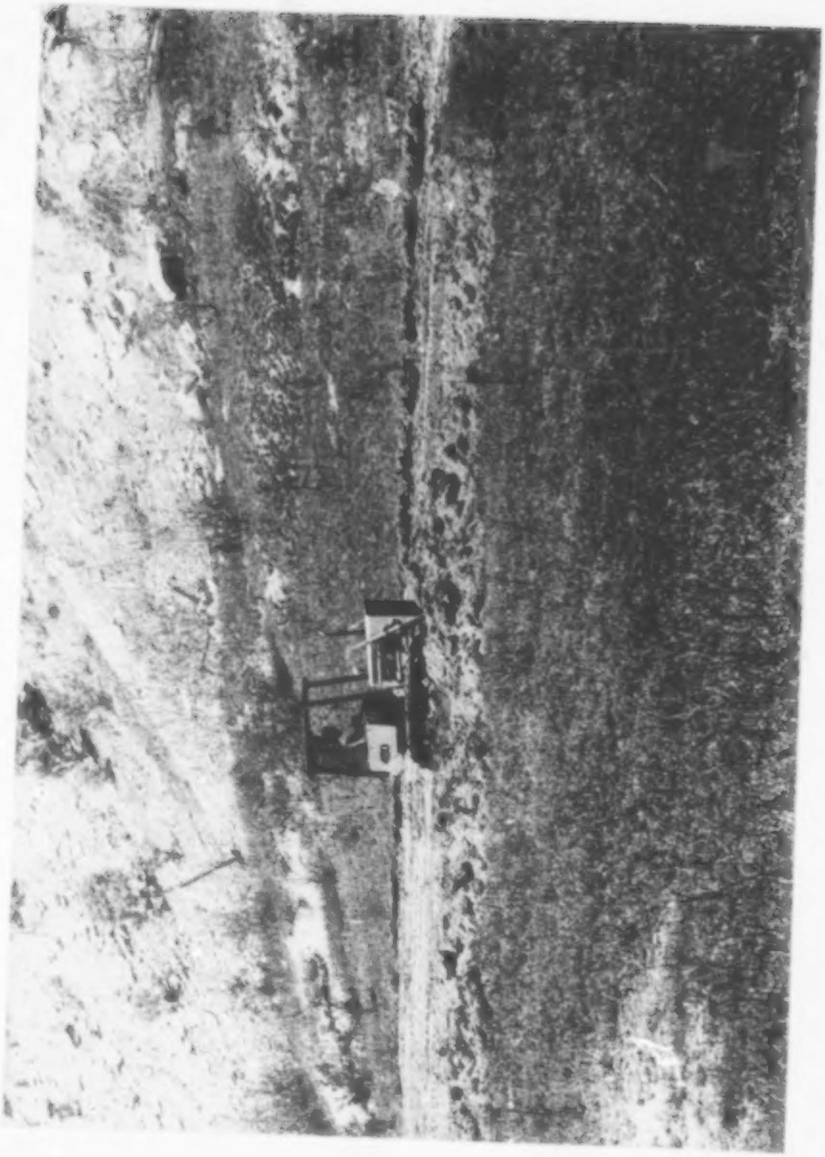


Figure 26. Removal of topsoil for stockpiling

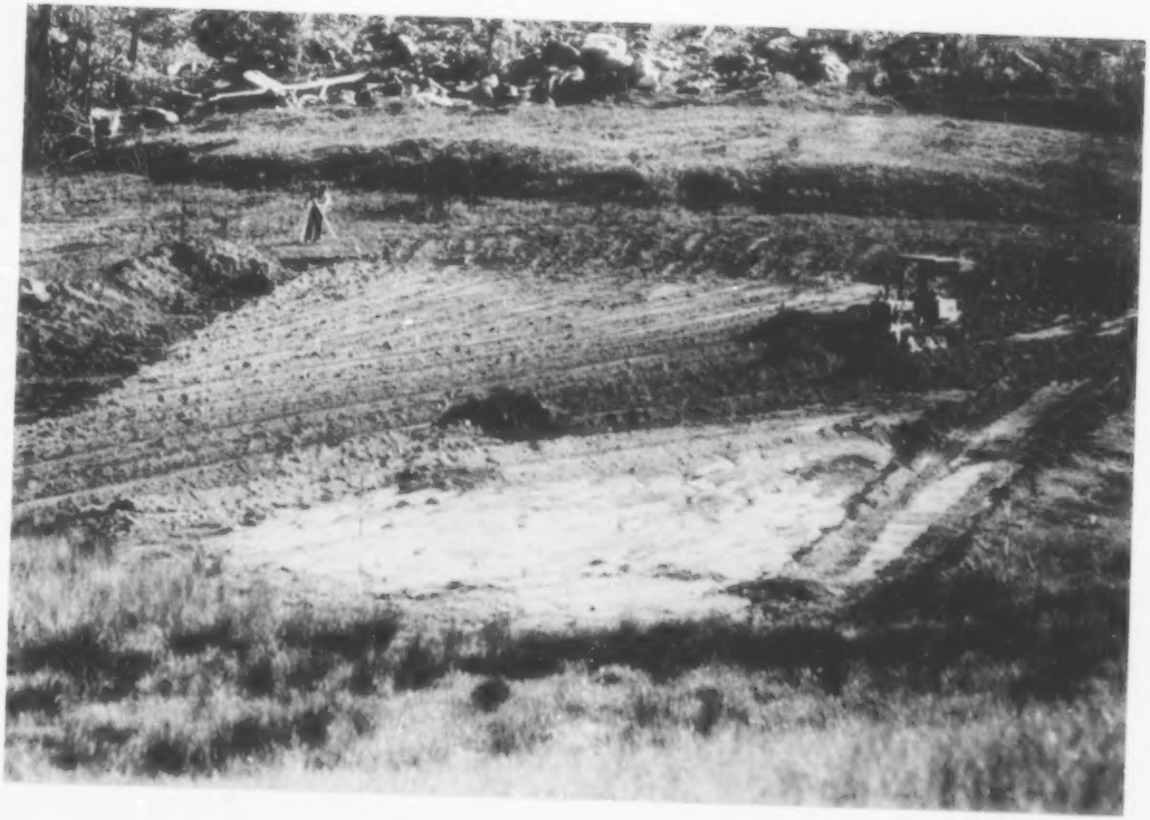


Figure 27. Rough grading of the subsoil

after soil testing specified an application rate of agricultural lime of five tons per acre. This translated to about 3700 pounds (1678 Kilograms) of lime for the filter area. Instead of incorporating the entire amount of lime into the topsoil, approximately 1200 pounds (544 Kilograms) was applied between the topsoil and subsoil, thus providing an "alkaline barrier". In theory, this barrier might lessen the effects of the strongly acid subsoil on vegetative growth.

In the initial stages of leveling the area on the required slope, approximately 1720 cubic meters of material were moved. The following replacement of topsoil involved the movement of 573 cubic meters of the original 1720 cubic meters for a second time.

Topsoil was replaced over the entire area to a depth of from 10.2 to 15.3 centimeters (Figure 28). A level surface was obtained by driving stakes into the subsoil to a previously marked position and stretching a nylon string between the stakes 12.7 centimeters above the subsoil. This method was utilized every 6.1 meters, over the 41 meter length of the area. As the string was positioned, the bulldozer operator filled or cut to the string. Although the process may appear time-consuming, the work was accomplished quickly.

One very important factor often overlooked in soil handling practices is the weather constraints. The weather's influence on the success of grading operations is greatly intensified if the slope area is steeper than two to five percent. Under spring storm conditions, when rainfall intensities are sometimes very high, the loosely regraded topsoil may be lost to erosion. Planning the installation of a vegetative filter should always include planning for optimum weather conditions. During the course of the installation of the filter, pollution by erosion was controlled by several methods. One of these methods was the use of a straw bale dike (Figure 29).

VETETATIVE ESTABLISHMENT AND PERFORMANCE

Fertilization and seeding activities were planned to begin immediately after the bulldozers completed the required grading. The only fertilization done prior to this was the application of 1200 pounds (544 Kilograms) of lime between the topsoil and subsoil to serve as an "alkaline barrier".

An additional 2500 pounds (1134 Kilograms) of lime was applied to the surface, along with the recommended amounts of phosphorus and potassium. The fertilizer was broadcast with cyclone seeders and all three materials were disced

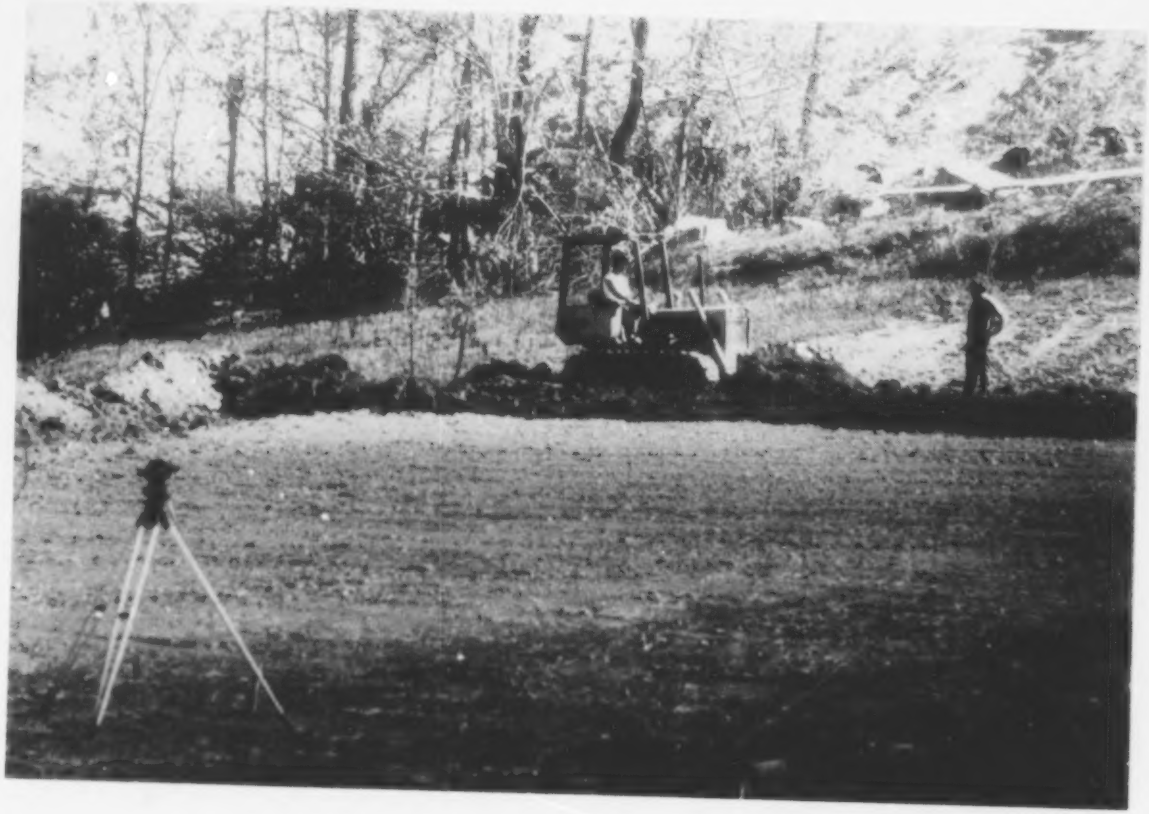


Figure 28. Stockpiled topsoil replacement

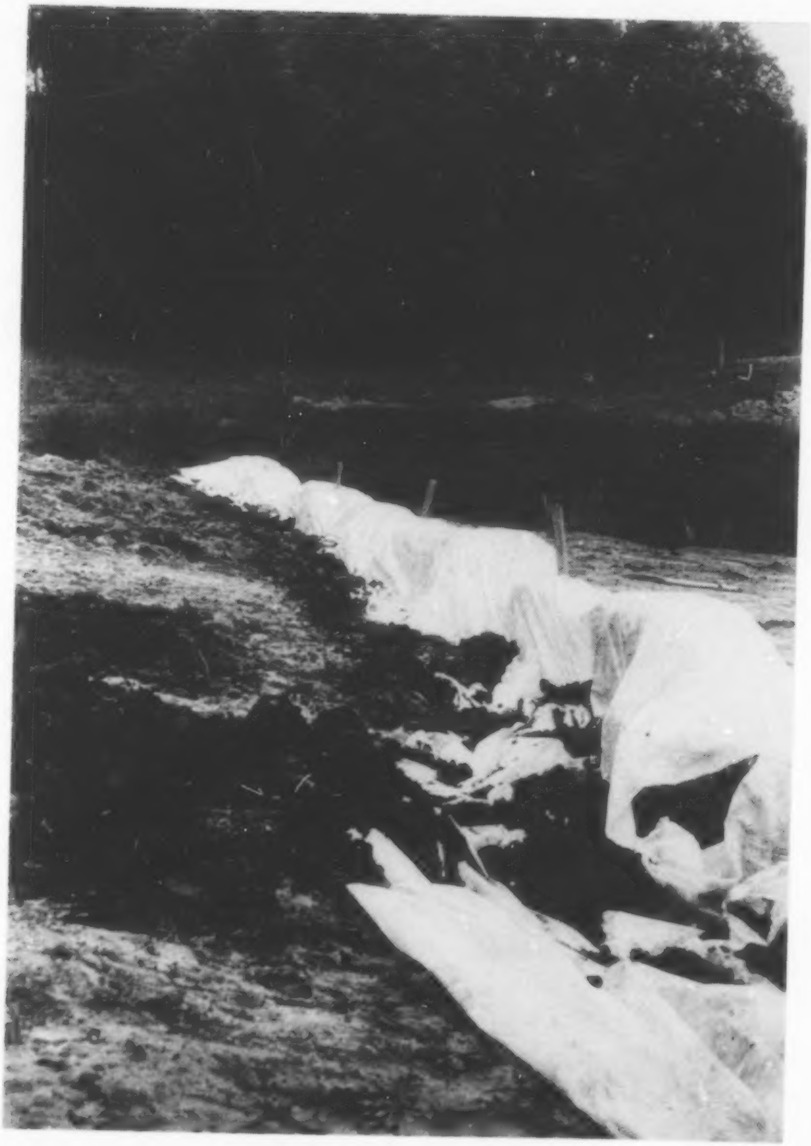


Figure 29. On-site erosion control using a straw bale dike

twice into the topsoil with a straight disc to a depth of 10.16 centimeters.

The seeders criss-crossed the area two times from different directions to ensure accurate seed distribution. The topsoil was then lightly disced to cover the seed and promote good soil seed contact. In addition to increasing germination, covering the seed was intended to reduce seed loss through erosion, a distinct possibility on the 17 percent slope. After the seed was covered, a heavy rye-straw mulch was applied to the area for erosion control.

From the time of seeding on May 15, 1979, the vegetative growth was checked weekly to accurately monitor progress. Heavy rainfall made adequate establishment questionable, but because of a diversion cut across the top of the study area to divert flow away from the filter, no major damage resulted. On May 31, 1979, when the vegetation reached a height of 7.62 centimeters, an additional 10 pounds (5 Kilograms) of actual nitrogen was applied to the site. This is a common practice in the management of turfgrass and, with the increased seeding rate, the additional nitrogen was needed to speed the vegetative establishment.

The first problem in establishment became evident in early June. Covering the seed with the disc increased germination, but resulted in some rows of dense vegetation throughout the area. The fact that these rows ran up and down the slope increased the nature of the problem. It was evident that the area had to be reseeded to establish a filter medium of uniform density. After scarifying the surface, tall fescue seed was broadcast and 30 pounds (14 Kilograms) of nitrogen applied. After seeding and fertilization, 1200 pounds (544 Kilograms) of lime was applied to the acid area at the top of the study site. Following the second seeding, a mowing management routine was imposed to reduce competition with the new seedlings. This work corrected the problem, resulting in vegetation of the high quality shown in Figure 30.

Extreme drought conditions in the area necessitated installation of an irrigation system to relieve the water stress. On August 17, 1979, Savoy Coal Company's water truck was made available to transport water from a nearby sediment pond to the filter area. Plastic (PVC) pipe was attached to the truck with a dam-lock coupling and the water pumped 192.9 meters down the outslope, through Rainbird 40 sprinklers, and onto the area. Approximately 1.27 centimeters of water was applied. The irrigation relieved the stress and ensured vegetative success.

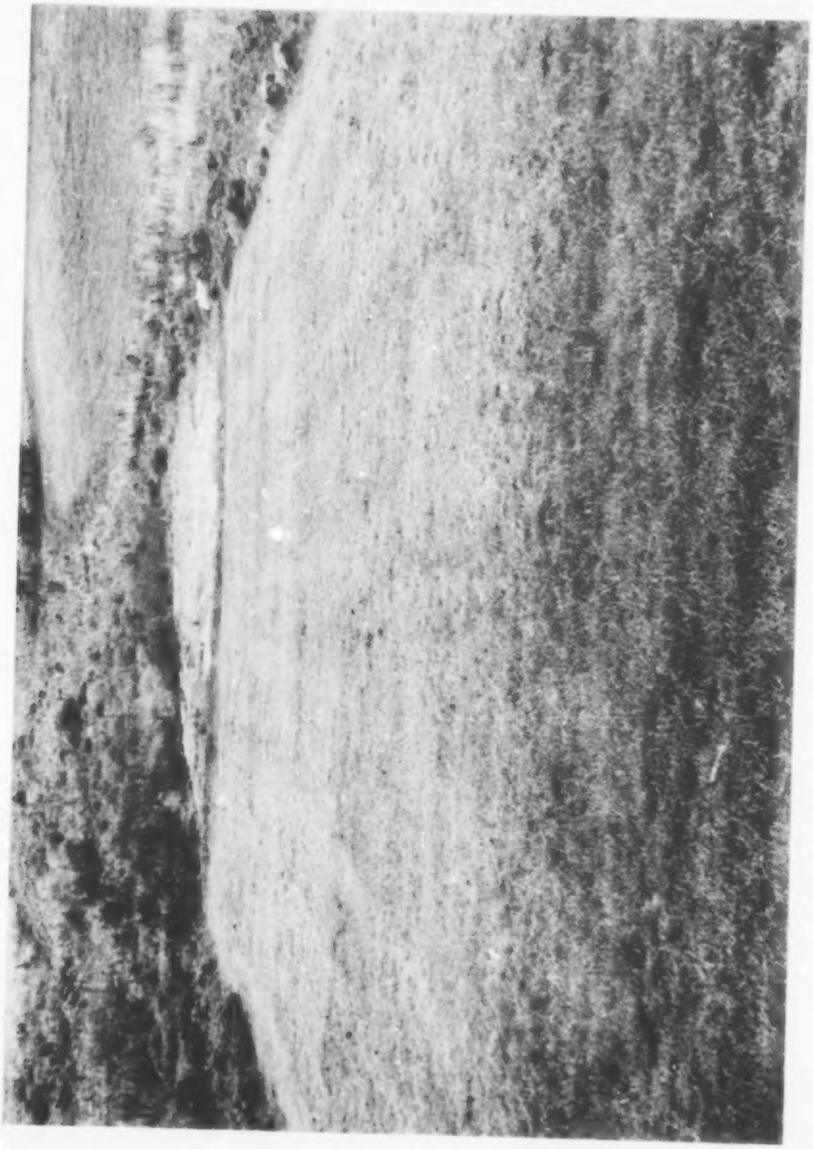


Figure 30. Fescue and Ryegrass after maturity

Vegetative Maintenance

During the course of the monitoring period, the degree of maintenace required was governed by vegetative growth. The only major nutrient problem encountered was a nitrogen deficiency. The characteristic yellowing of the vegetation gave good indication that nitrogen was insufficient. This deficiency was corrected by broadcasting nitrogen, on two separate occasions, at a rate of 50 pounds (23 Kilograms) per acre. The acid conditions that had existed at the top of the filter due to acid inflow were corrected with the previously discussed application of lime. To ensure erect growth of the vegetation, a mowing plan was established. Under the stress of high flow conditions, the vegetation would lay over and create a grass waterway effect. Three mowings of the filter were sufficient to keep the grass in an erect growth habit.

Vegetative Performance

Overall, performance of the vegetation during the project time frame was excellent. The key to such success is to plan as thoroughly as possible before going into the field. As previously noted, the two major problems encountered were soil and runoff acidity during establishment and nitrogen deficiencies after vegetative maturity. Other than these two problems, little difficulty was experienced relative to vegetative performance.

Deposition of fine-grained sediments in the filter area were concentrated in the upper areas, although some deposition did occur throughout the filter. During one storm, which exceeded a 100 year event, rocks 7.62 centimeters in diameter were washed 12 meters into the filter area. Even under these extremely high flow conditions, the vegetation was not uprooted.

Erosion within the filter area was a real concern throughout the course of the project. This concern was alleviated with the installation of a flow divider network to spread the flow across the top of the filter to prevent channelization. Without this flow divider, the concentrated flow on the inlet area would have caused severe damage. The following section will discuss both the details of the design and installation of flow dividers and level spreaders.

WATER MONITORING SYSTEM INSTALLATION

When the established vegetation reached a density sufficient to resist erosion and support the stresses of vegetative filtration, the monitoring system was installed.

Installation was accomplished through a cooperative effort between Hittman Associates, Inc. and the University of Kentucky, College of Agricultural Engineering.

Section four presented the preliminary design considerations for the filter area and the monitoring system. This section applies the design criteria, described in section four, to the field study site to create a complete, functional system. The monitoring system installation process was broken down into several distinct steps, including:

- preliminary site alterations,
- location of footers for flume implacements,
- installation of flume implacements,
- installation of flow divider and level spreader network,
- placement of equipment housings,
- monitoring equipment installation, and
- system calibration

Preliminary Site Alterations

Before any work could begin, the positions of the inflow and outflow flume supports had to be marked in the study area. The positions were marked by measuring the halfway point in the area with a metal tape. The positions for the level spreaders would also be utilized to achieve an equal distribution of flow across the filter area.

Once preliminary measurements were completed, the actual site alterations began. A backhoe was utilized to dig the trenches for the footers previously marked. The depth of each hole was checked to ensure that the flumes would be at the correct height once they were installed. The final site alteration involved cutting diversions with the bulldozer on the contour to divert the water into the inlet flume. These diversions were cut to a .46 meter depth and an 2.44 meter width (Figure 31). In addition to the diversions, overflow channels were cut to divert water around the filter area during large storm events. These overflow channels were designed to divert runoff greater than a ten-year event and divert them into a straw bale dike.

Placement of Footers for Flume Implacements

In order to avoid problems with future maintenance, the flume implacements were set on a 30.5 centimeter concrete footer. Concrete delivered to the site proximity in a commercial concrete truck was transported to the site in a backhoe shovel. The footers for each of the flume implacements were poured to the same level position by alignment with

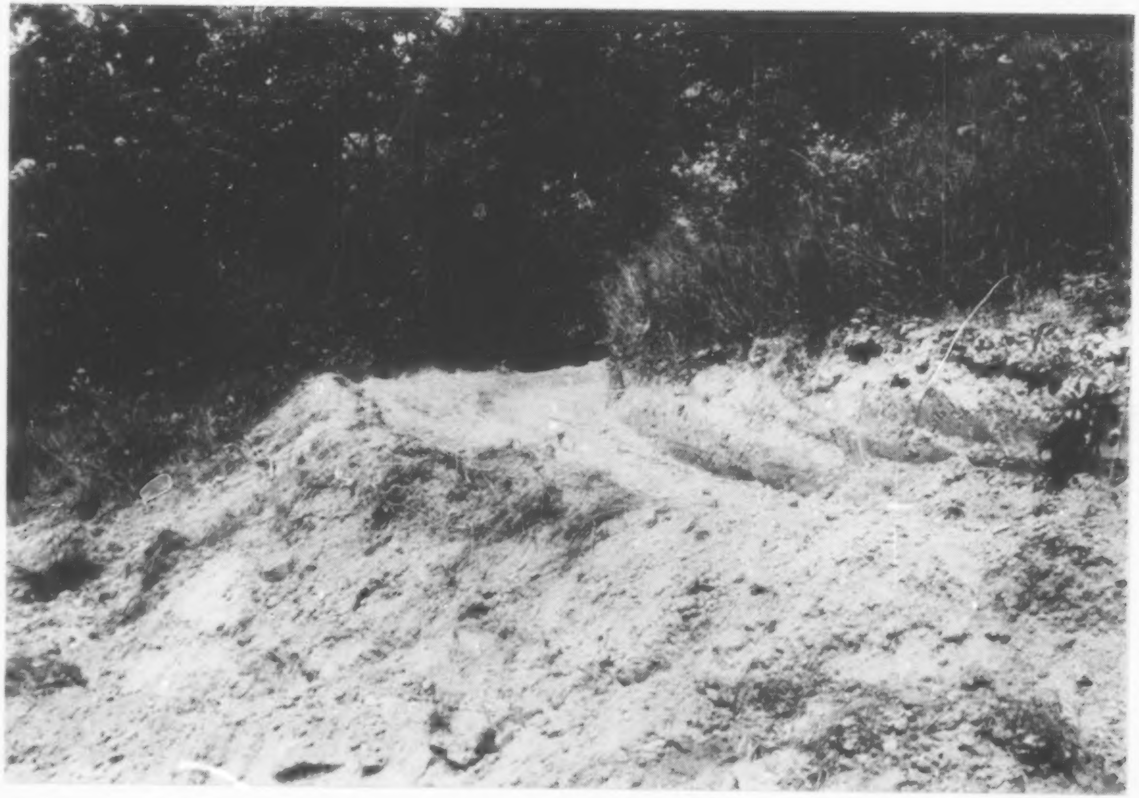


Figure 31. Diversions to direct flow into the filter area

previously surveyed stakes set in the bottom of the trenches (Figure 32).

Installation of the Flume Implacements

After allowing the concrete footers to dry and set up the concrete block, flume supports were constructed for both inlet and outlet monitoring stations. Detailed plans for these supports are shown in the third section, under water monitoring system design. Concrete block were used to construct two support walls on both ends of the study area. During the construction of the supports, the H-flumes were positioned and mounted as shown in Figure 33.

Installation of Flow Divider and Level Spreader Network

The specialized flow divider was installed directly below the inlet flume spreader box (Figure 34). The function of the spreader box was to spread the flow before the water dropped into the flow divider mechanism. Both the spreader box and flow divider were anchored in place by 1.27 centimeter angle iron set in the subsoil.

A level spreader was installed approximately three meters below the metal flow divider. The spreader extended the full 20.73 meter width of the filter. Initially, the 3.05 meter lengths of wooden spreaders were connected together with truss-plates to form one large section. One side of the board was coated with a tar sealant and four (4) mil. plastic sheet was attached with roofing nails (Figure 35). The entire section was then placed in the trench and the plastic pulled downslope to expose the 3.05 meters of bare soil.

This bare soil area is where the 2 x 4 inch (5 x 10 centimeter) flow dividers were to be anchored. The base plates of the flow divider were laid out radiating from the central metal flow divider and soil was filled in between the dividers (Figure 36). The plastic connected to the level spreader was then pulled up the slope to cover the plates. The second set of treated flow dividers were measured and nailed to the lower plate, leaving the plastic in between. Metal strips were used to connect the wooden dividers with the metal flow divider. The entire flow divider, level spreader network was anchored to the subsoil using steel rebar stakes, 46 centimeters in length. The completed flow divider network is shown in Figure 37.

A plastic lined collection system was installed at the downstream end of the filter to convey water from the filter to the outlet flume (Figure 38). A level spreader, similar to that used with the flow divider network, was used to

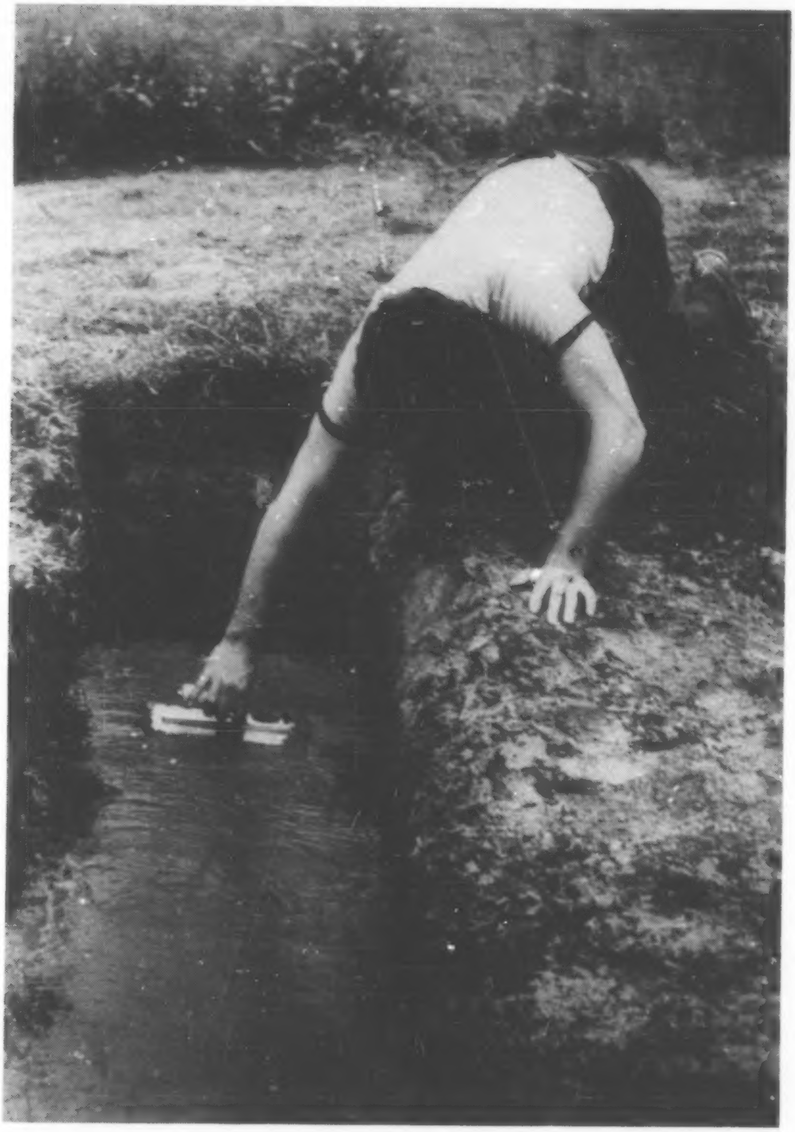


Figure 32. Leveling concrete for flume supports

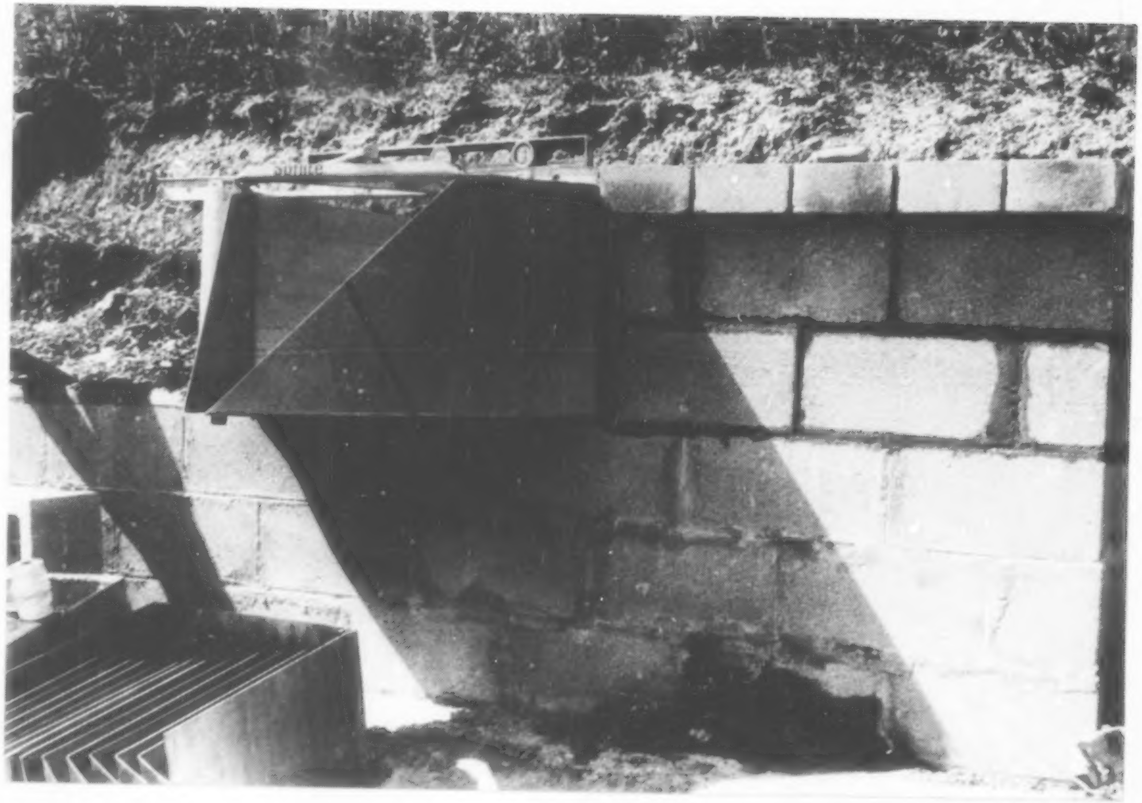


Figure 33. Positioning of H-Flumes

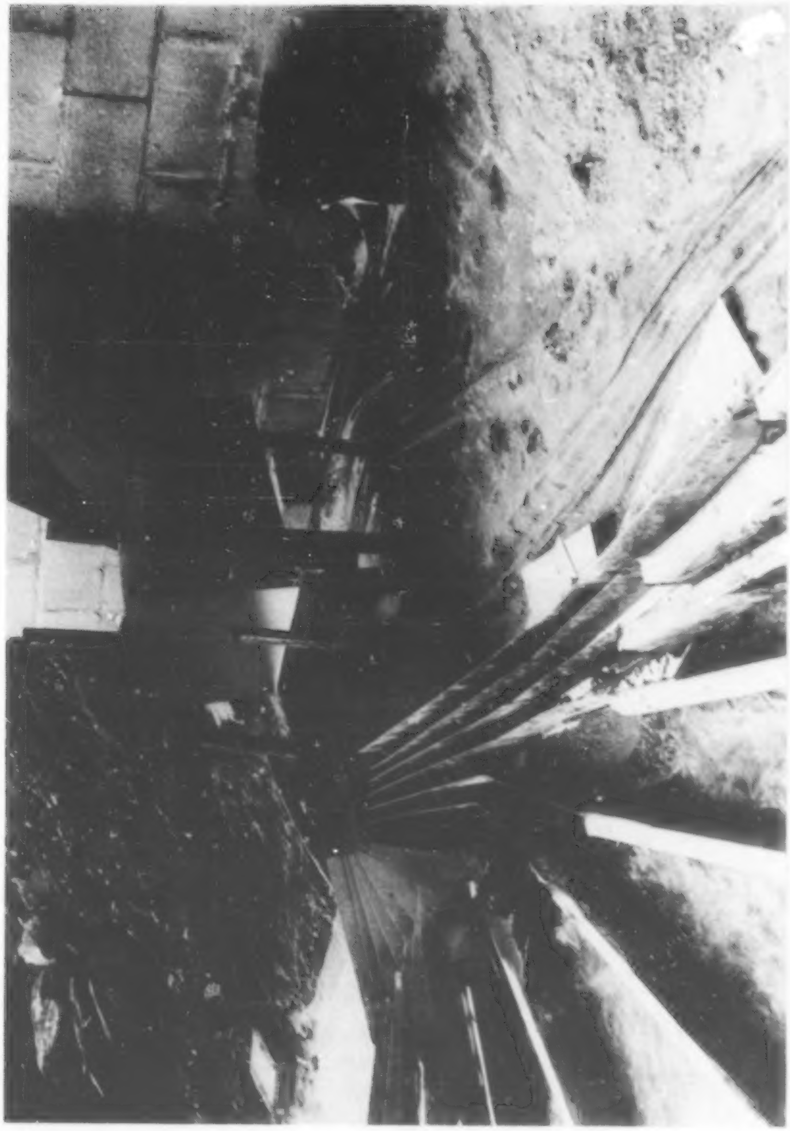


Figure 34. Placement of metal flow divider

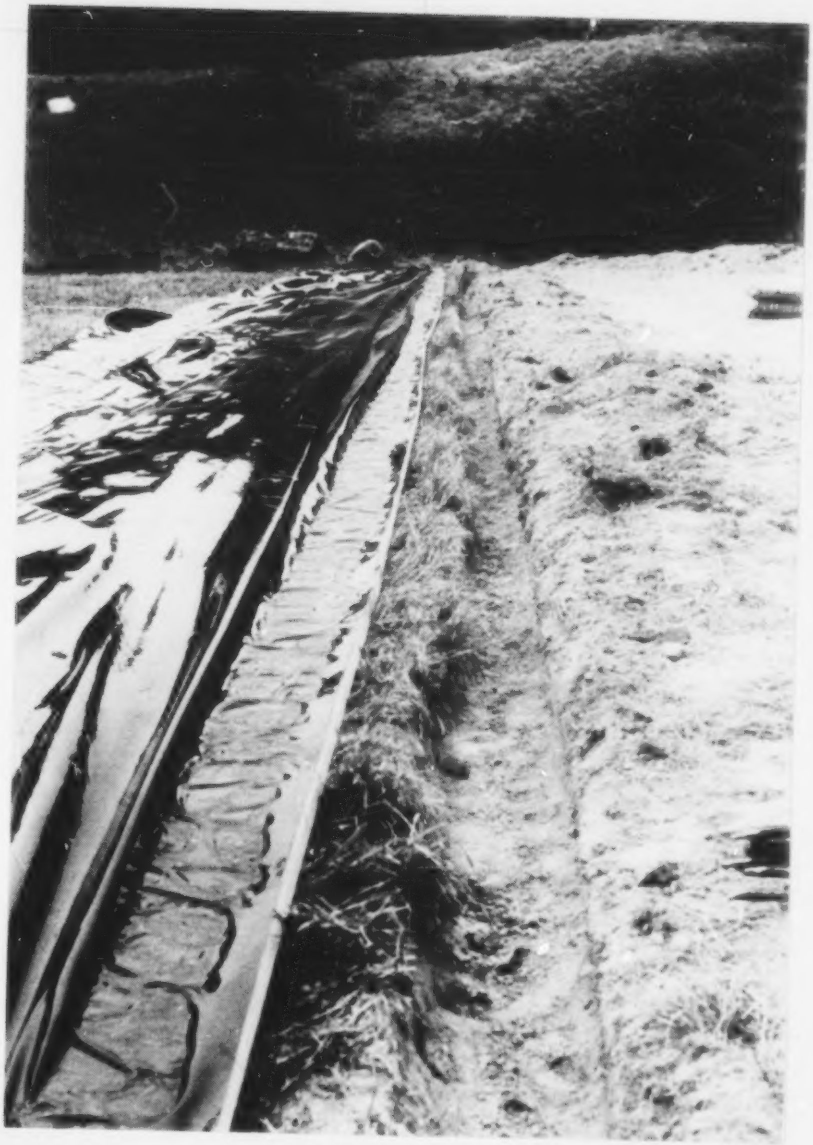


Figure 35. Attachment of 4 mil. plastic to level spreader

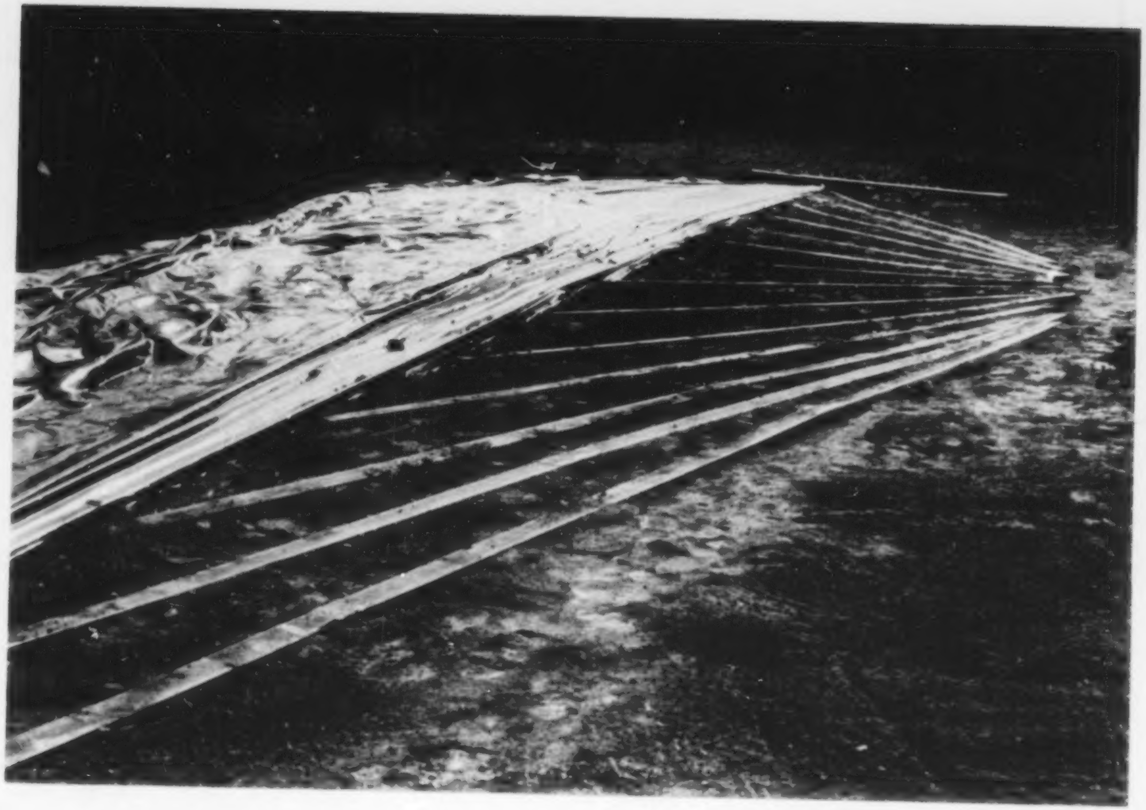


Figure 36. Soil filling between 2 x 4 flow divider plates

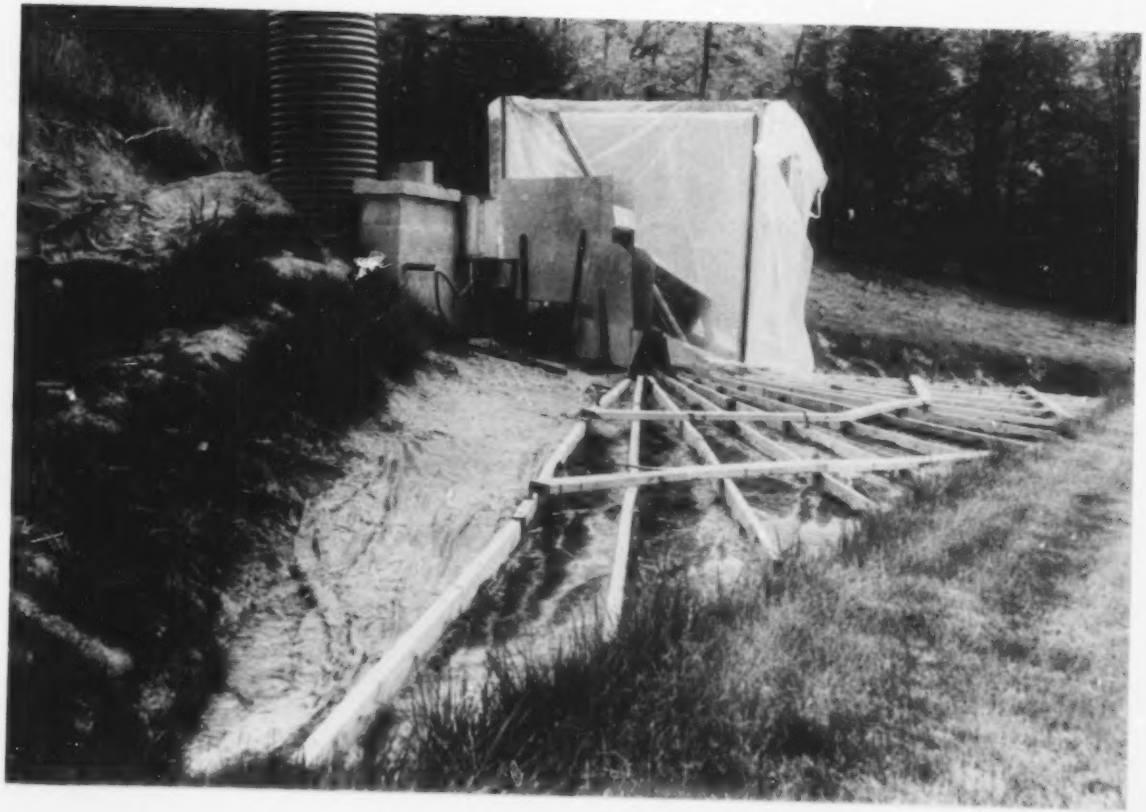


Figure 37. Completed flow divider network

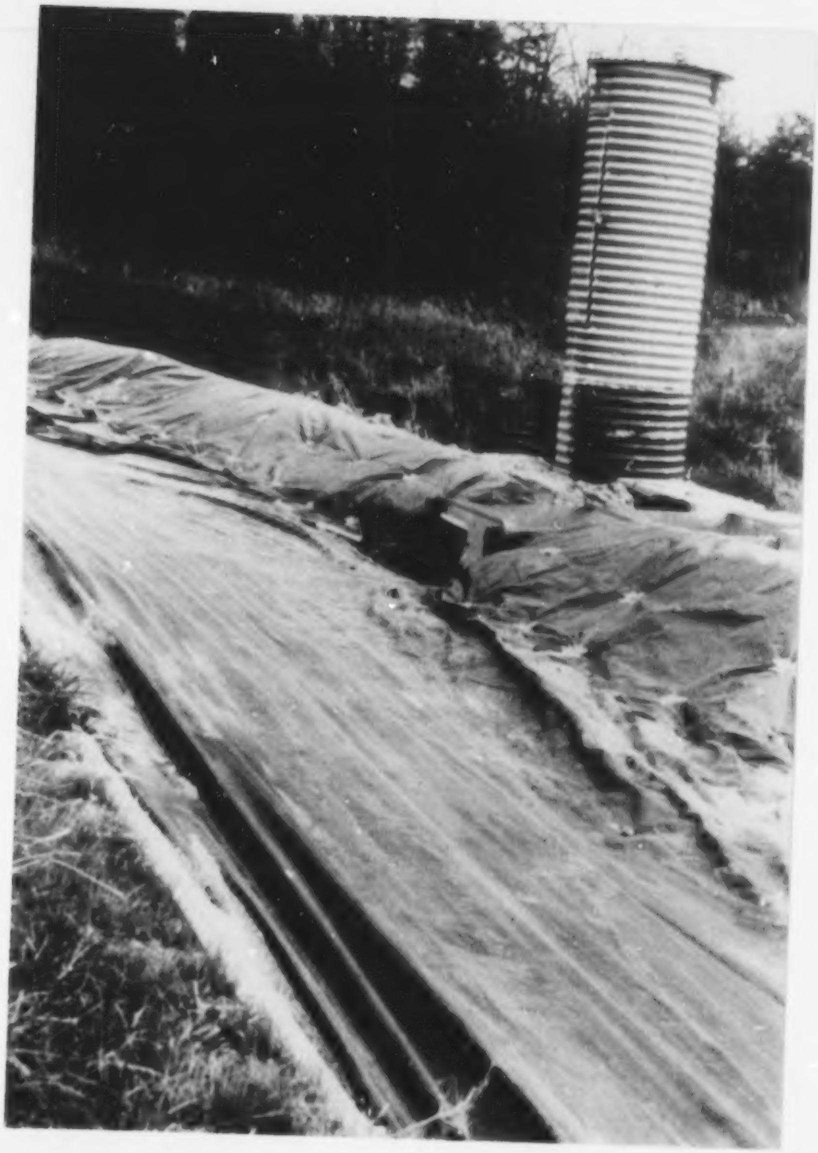


Figure 38. Plastic diversion leading to lower flume

anchor the plastic lining at the downstream edge of the filter. The outlet level spreader and plastic diversion were constructed to funnel the flow into the outlet flume (Figure 38).

Placement of Equipment Housing

The equipment housings installed to protect the instrumentation from weather and theft consisted of corrugated steel pipe modified to contain the monitoring system equipment. These enclosures were set in place by anchoring the bases in the subsoil and compacting soil around the pipe.

Monitoring Equipment Installation

The following discussions of the equipment installations are applicable to both the inlet and outlet monitoring stations.

The Isco automatic samplers were installed in small culvert housings. From the sampler, the collection tube extended to a point directly below the flume, where a special collection device was installed. This device is shown in detail in the design drawings in Section 4.

To maintain an accurate record of sample collection, an event marker was installed on the Stevens water stage recorder. The event marker was actuated by an electrical connection between the sampler and the Stevens recorder and placed a mark on the chart paper when the sampler was activated.

The activation of the samplers was controlled by electric water level sensors mounted in stilling wells installed at the side of the H-flumes. When the stage reached a predetermined level in the flume and stilling well, the water level sensors activated the samplers. The samplers continued to collect samples throughout the storm event until the water level again dropped below the sensors.

The Stevens water stage recorder was also activated by the changing water levels in the stilling well attached to the flume. A tube attached to the stilling well governed the level of a float in an additional well in the base of the equipment housing. The Stevens recorder operated with a standard float mechanism and spring-wound chart drive.

A Weathermeasure 30 centimeter raingauge was set in concrete at the base of the filter area. The completed inlet and outlet monitoring stations installed on the filter site are shown in Figure 39.

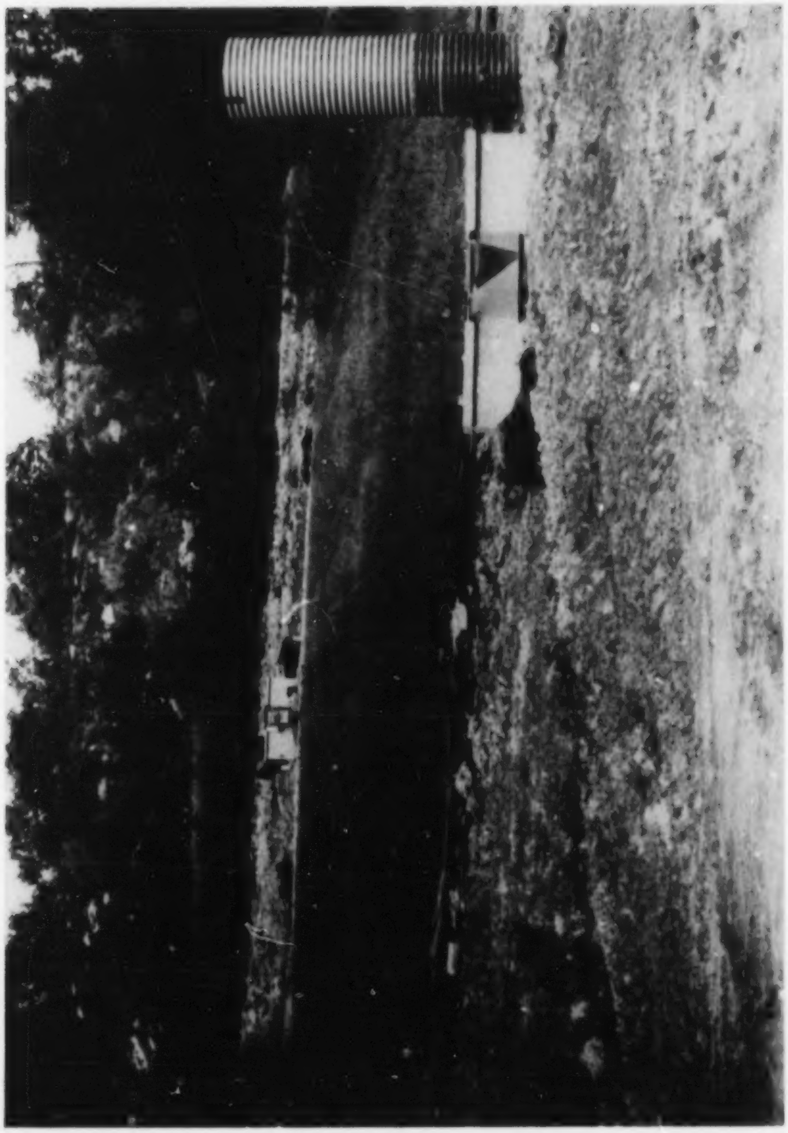


Figure 39. Completed inlet and outlet monitoring stations

System Calibration

In order for the system to function properly, the time of inflow and outflow sampling had to be coordinated. The delay time of inflow into the filter and the outflow was very important for accurate sample collection. The sampler activators for inflow were set higher than those for outflow, so that the inflow sampler would not run out of sample bottles before the outflow sampler in the event of long duration rainfall.

The water stage recorders were set to zero by priming the connection hoses with water and adjusting to zero. Initial testing of the inflow and outflow stations was accomplished by simulation of a storm event. According to plan, the automatic samplers were then programmed to sample every ten minutes during a storm event.

TIME AND MATERIAL REQUIREMENTS OF FILTER INSTALLATION

Table 11 lists the approximate number of labor hours required to install the vegetative filter used during the demonstration project.

TABLE 11. APPROXIMATE NUMBER OF MANUAL AND EQUIPMENT HOURS REQUIRED FOR FILTER INSTALLATION

Activity	Manual Hours	Equipment Hours	Total Hours
Topsoil Removal	4	2 1/	6
Grading	18	6 1/	24
Topsoil Replacement	4	2 1/	6
Soil Preparation	4	2 1/	5
Fertilization	4	-	4
Seeding/Mulching	10	-	10
Follow-up Maintenance	4	-	4
TOTALS	48	11	59

1/ Small bulldozer

2/ Small Tractor and Disc

TABLE 12. TYPE AND AMOUNT OF MATERIALS REQUIRED FOR FILTER INSTALLATION

Material Type	Amount/Applied
Lime	3,700 lbs. (1678 Kg.)
Nitrogen	30 lbs. (15 Kg.)
Phosphorus	55 lbs. (25 Kg.)
Potassium	34 lbs. (15 Kg.)
Seed	70 lbs. (32 Kg.)
Mulch	3 tons/acre (6804 Kg./hectare)

These figures were applied to create a level filter area, 41.0 by 21.0 meters on a 17 percent slope.

Table 12 lists the type and amount of materials used. The hours shown in Table 11 reflect only the time required for filter installation, and do not reflect the time required for related activities such as engineering design, surveying, installing the monitoring network, constructing the access road, etc. Although the figures in Table 11 and 12 may provide a general indication of time and material costs for a vegetative filter, they apply specifically to the study site and should not be used for cost estimates on vegetative filters of varying sizes and/or uses.

SECTION 6

SEDIMENT AND WATER QUALITY MONITORING

SAMPLING PROCEDURES

The original project proposal called for the installation of one H-flume and water stage recorder at the inlet to the filter to measure runoff. In addition, bi-weekly grab samples were to be used to measure sediment concentrations. These sampling procedures would not yield enough data to validate several available computer models pertaining to the sediment filtration capacity of vegetation. Since researchers at the University of Kentucky were interested in further evaluation of their models, an informal agreement was reached whereby automatic samplers available to the University could be used at the inlet and exit of the filter to measure concentrations and flow rates. In conjunction with periodic hand sampling, it was hoped that adequate data could be collected to validate the University of Kentucky computer model as well as evaluate the effectiveness of the vegetative filter.

As discussed in the description of the water monitoring system in Section 5, two automatic pumping samplers were used, along with two H-flumes to monitoring inflow and outflow water rates and sediment concentrations. In order to obtain a complete data set for any storm, both samplers had to activate and run properly and both water stage recorders had to operate and ink properly. This did not happen in all of the storms over the one-year monitoring period. Siltation of the H-flumes was also a problem, particularly in the inlet flume. This siltation caused a shift in the calibration curves, therefore, the flow rates calculated from water stage data are subject to some error. For future experimentation, the use of a drop box weir or a sloping H-flume would be recommended. For the reasons mentioned, hand sampling was also accomplished for some storm events.

Hand sampling consisted of the use of project personnel at the inlet flume and the outlet. Upon collection of each sample, a reading was taken from a point gauge mounted in the flume (Figure 40). Sampling continued through the duration of the storm event.

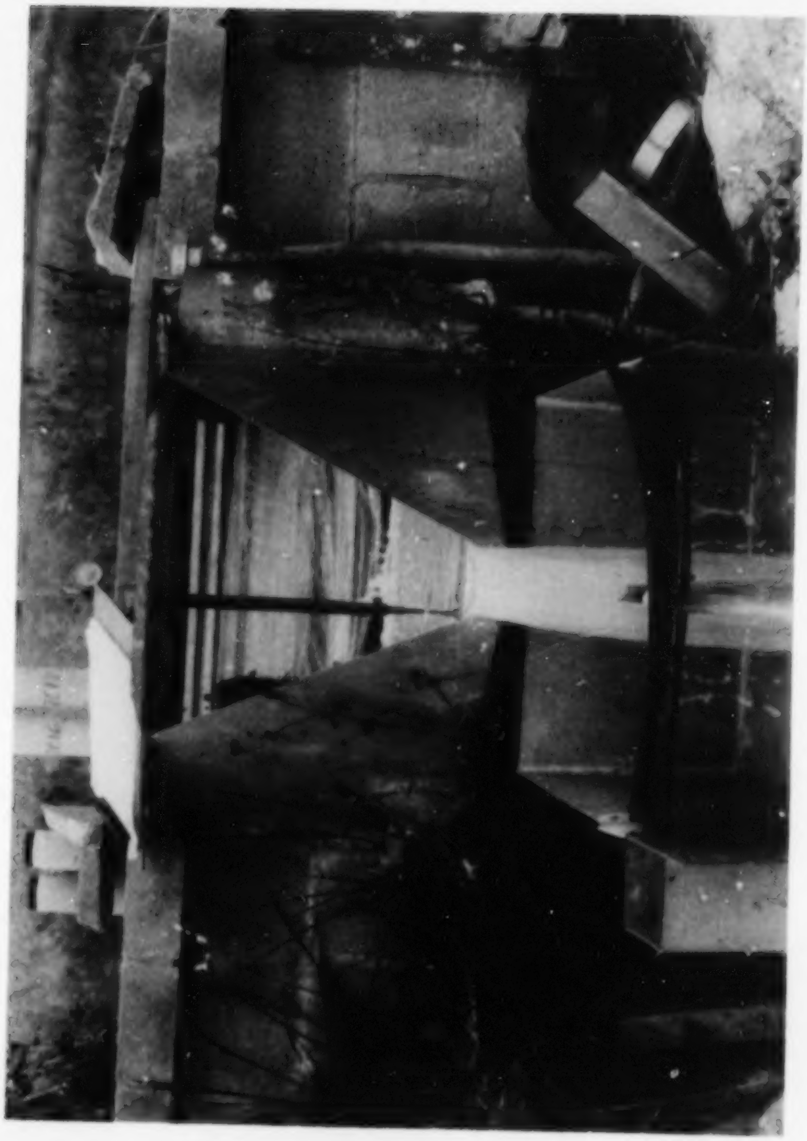


Figure 40. Point gauge mounted in H-Flume for use in hand sampling

LABORATORY ANALYSES

The University of Kentucky, College of Agricultural Engineering, performed all analyses of the water and sediment samples collected during the course of the demonstration project. This entailed testing for total sediment concentrations of inflow samples, outflow samples, and performing periodic size distribution measurements of the trapped sediment. Results of the monitoring and testing program are depicted graphically in the following section of the report. The actual methods for testing are shown in Appendix C.

All soil testing for fertility required in vegetation establishment was performed by the University of Kentucky Soil Lab. Soil samples from the filter study area and spoil samples from the drainage area were tested for pH, phosphorus and potassium.

Quality control on the analysis of the water and sediment samples was achieved by sending duplicate samples to the Hittman Laboratory in Columbia, Maryland. No problems with the laboratory results surfaced over the course of the project.

SECTION 7

DESCRIPTION OF RESULTS

BACKGROUND AND CALCULATIONS

The filter was constructed in the late spring of 1979. The flow was diverted away from the filter area while vegetation was being established. Flow was diverted into the filter in the late fall of 1979 and monitoring equipment installed. During the months of January and February, the monitoring equipment was removed to prevent freeze damage. During that period, storms were hand-sampled whenever possible. Monitoring equipment was reinstalled in the spring of 1980, and monitoring continued until November, 1980. During the montoring period, several storms of sufficient magnitude occurred to cause runoff and flow through the filter. One storm, with a duration equal to two hours, had a return period of over 100 years. The data from these storms are presented in the following sections.

Calculations utilized in the storm data evaluations are discussed below:

- Trapping efficiency, Tr, can be estimated by:

$$Tr = \frac{M_i - M_o}{M_i}$$

where M_i and M_o are the total mass of sediment in the inflow and outflow.

- The mass of inflow on outflow can be predicted from:

$$M_i = \sum_{j=1}^{n} C_{ij} \, q_{ij} \Delta t_j$$

where C_{ij}, q_{ij}, and Δt_j are the sediment concentrations, flow rate, and time interval of the jth element of inflow. M_o can be calculated from:

$$M_o = \sum_{j=1}^{n} C_{oj} \, q_{oj} \, \Delta t_j$$

where C_{oj} and q_{oj} are the concentration and flow rate of the jth element of outflow. For some of the data sets, one set of the flow rates was either missing or unreliable, due to excessive sedimentation or failure of the water stage recorders to properly ink.

- For those cases where either inflow or outflow rates were missing, a very conservative estimate of trapping efficiency can be obtained from:

$$Tr = \frac{\bar{C}_i - \bar{C}_o}{C_i}$$

Where $\bar{C}_i$ is the average inflow concentration $\bar{C}_o$ is the average outflow concentration. This equation is typically conservative, since infiltration causes the outflow volume to be less than the inflow volume, unless the rainfall rate exceeds the infiltration rate.

The study data from the individual storm events are presented in the following sections.

STORM EVENT DESPCRIPTIONS

Storm of January 11, 1980 - An unusually warm period in January brought rains and runoff at the filter site. All equipment and records had been removed for the winter but the flow was hand sampled for a thirty minute period for sediment concentration only. No flow rates were measured. The results are plotted in Figure 41.

The storm did not generate massive amounts of sediment; the peak concentration was only 6,750 mg/l. Outflow concentrations were typically 500 to 600 mg/l, with the exception of one sample that was 1600 mg/l. Based on equation 7-4, ninety-two percent of the sediment was trapped in the filter area, indicating that the filter was performing well.

Storm of April 3, 1980 - On April 3, 1980, a complete data set was taken by hand sampling the inflows and outflows and by measuring flow depths in the H-flumes with point gauges. The results are shown in Figures 42 and 43. The size distributions of the sediment in the inflow and outflow are shown in Figure 44.

The peak inflow and outflow rates were 0.11 and 0.03 cfs (3.11 and .85 l/sec) respectively, indicating a significant attenuation of the flow rate, due primarily to infiltration. The infiltration volume was 54 percent of the inflow volume, as shown in Table 13.

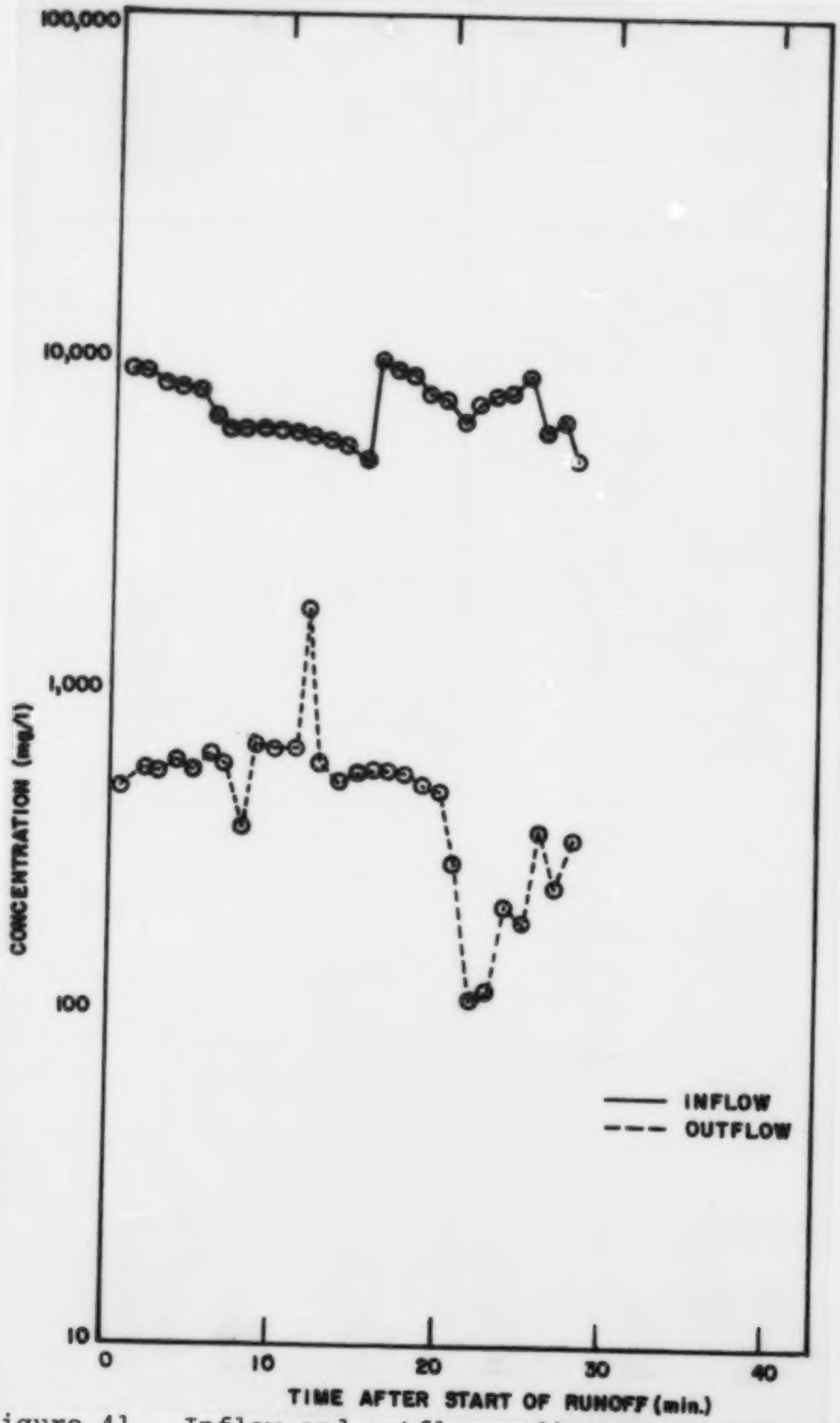


Figure 41. Inflow and outflow sediment concentrations for storm on January 11, 1980

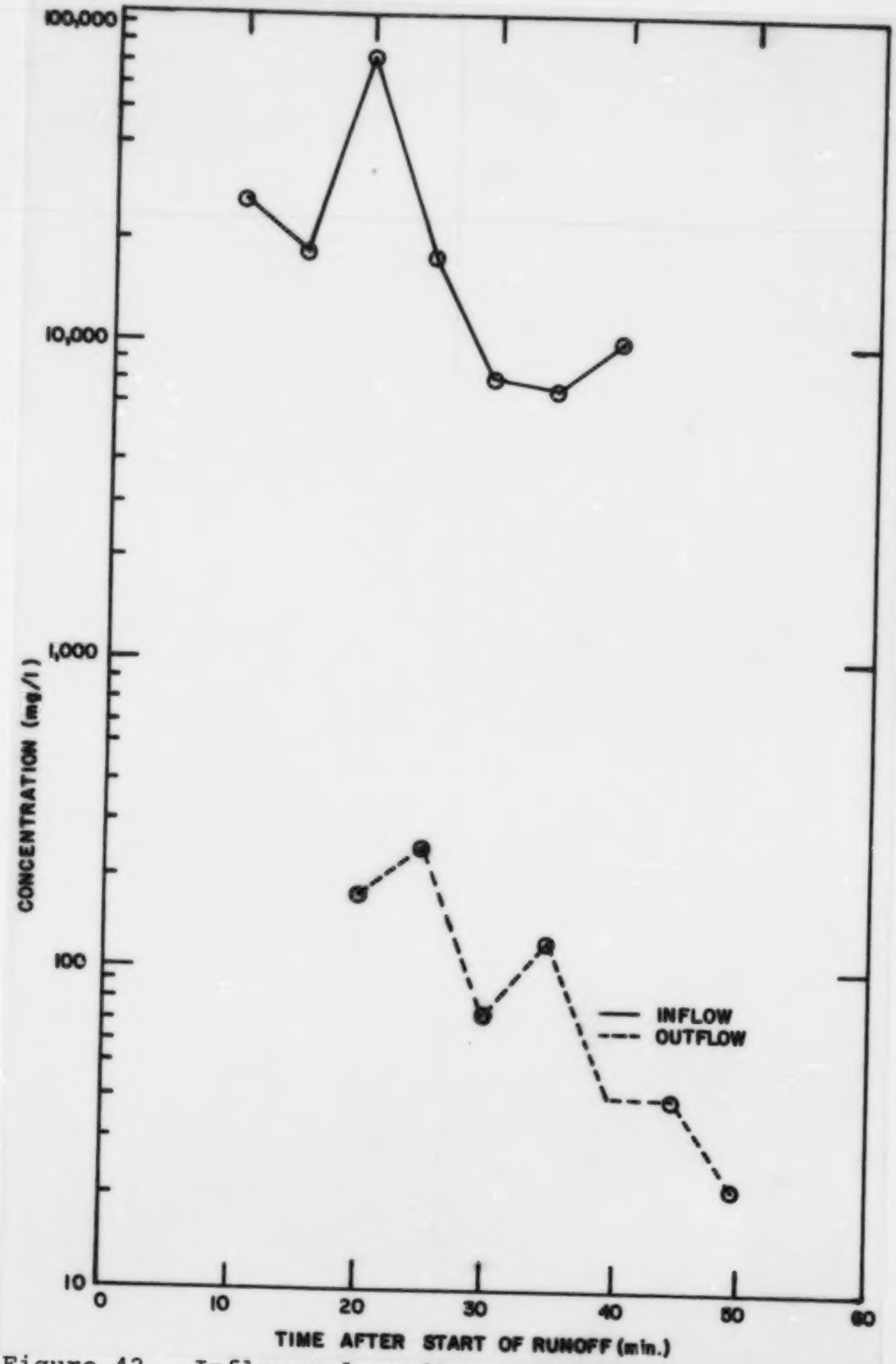


Figure 42. Inflow and outflow sediment concentrations for storm on April 3, 1980

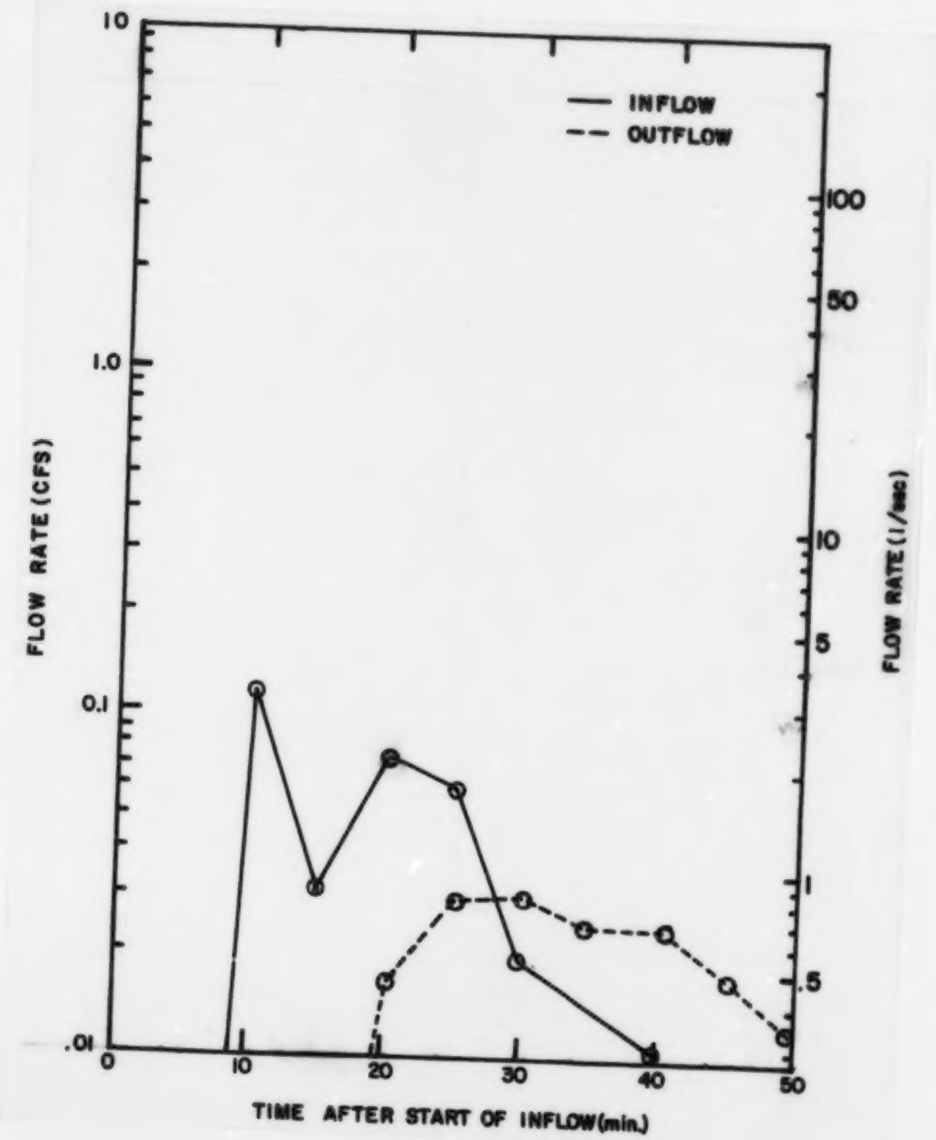


Figure 43. Inflow and outflow hydrograph for storm on April 3, 1980

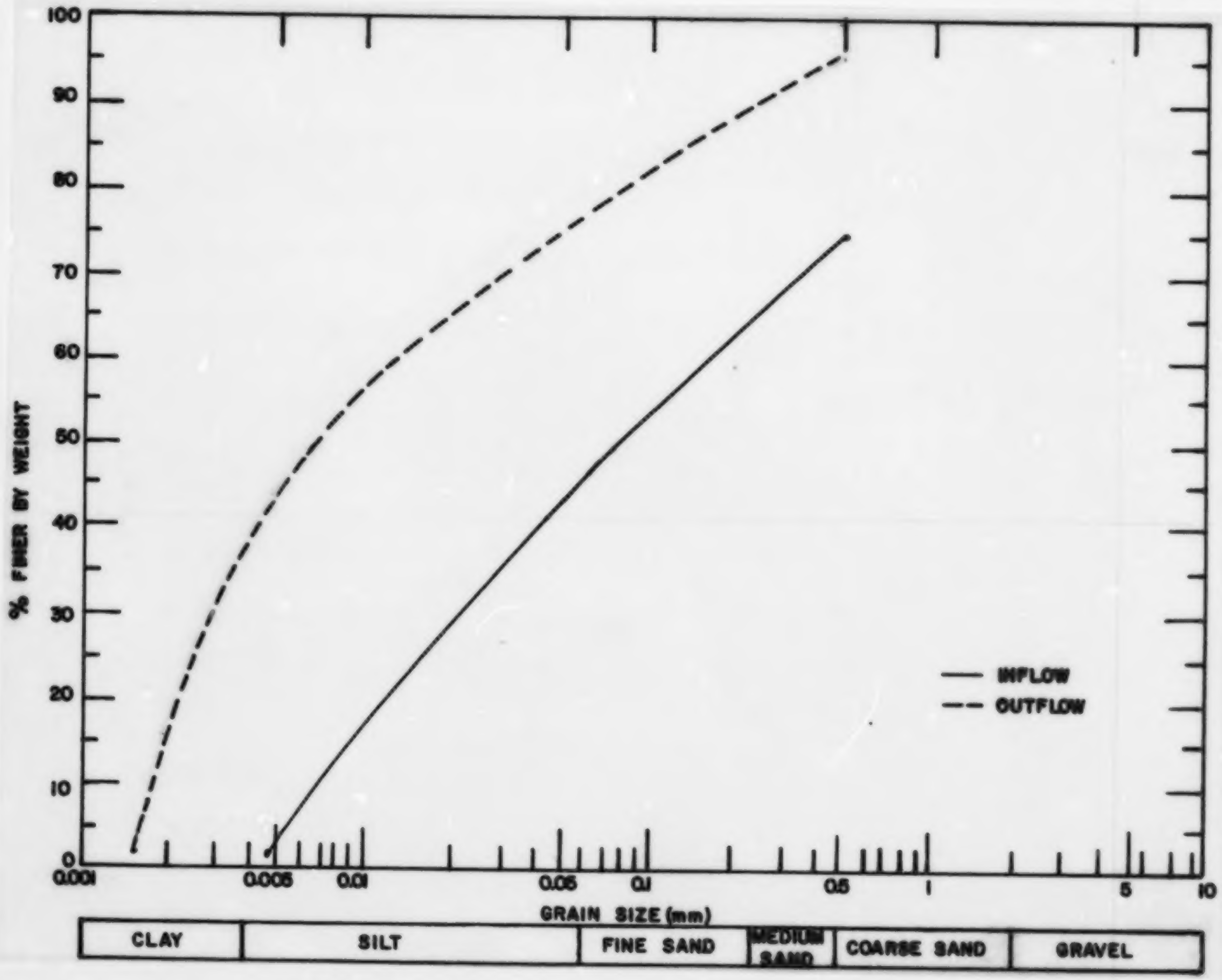


Figure 44. Aggregate size distribution of sediment for storm on April 3, 1980

The peak and average inflow sediment concentrations were 71,000 mg/l and 21,850 mg/l respectively. The peak and average outflow concentrations were 240 and 98 mg/l, yielding a trapping efficiency greater than ninety-nine percent. Again, in this storm, the vegetation did an excellent job of filtration.

The size distribution of the inflow sediment (on an aggregate basis), as shown in Figure 44, indicates that 99 percent of the particles were silt size or larger. This coarse size distribution explains the excellent trapping performance.

Observations were made of the flow patterns during the storm event. The flow was highly non-uniform, with flow fingering occurring at several locations across the filter. The fingering was a result of the longitudinal planting orientation of the filter up and down the slope. If the planting orientation and resulting roughness elements had been perpendicular to the slope, the flows would have been slower and the trapping efficiency should have been better.

Storm of April 11, 1980 - Runoff from the storm of April 11, 1980, was automatically monitored. The flow lasted for 105 minutes. Flow rates are shown in Figure 46. The peak inflow and outflow rates were 0.170 and 0.013 cfs. (4.81 and .36 l/sec) respectively, making the storm a small event. The volume of infiltration accounted for 79 percent of the inflow volume.

The inflow and outflow sediment concentrations are shown in Figure 45. Peak and average inflow concentrations are 6380 and 4800 mg/l. Peak and average outflow concentrations are 240 and 160 mg/l. The percent trapped is in excess of 99 percent. Again, the vegetation did an excellent job of filtering the sediment.

Storm of May 17, 1980 - Runoff from the storm of May 17 was monitored with automatic equipment. The flow lasted for 120 minutes, but flow through the filter apparently lasted only 30 minutes or less. Data plots are given in Figures 47 and 48. Peak inflow and outflow rates are 0.038 and 0.012 cfs. (1.08 and .35 l/sec). As a result of infiltration, eighty-five percent of the runoff did not appear as outflow.

Peak and average inflow sediment concentrations were 30,000 and 15,120 mg/l. Peak and average outflow concentrations are 4600 and 2967 mg/l. The trapping efficiency of the vegetation was 97.1 percent, below that recorded in earlier tests, but still highly acceptable.

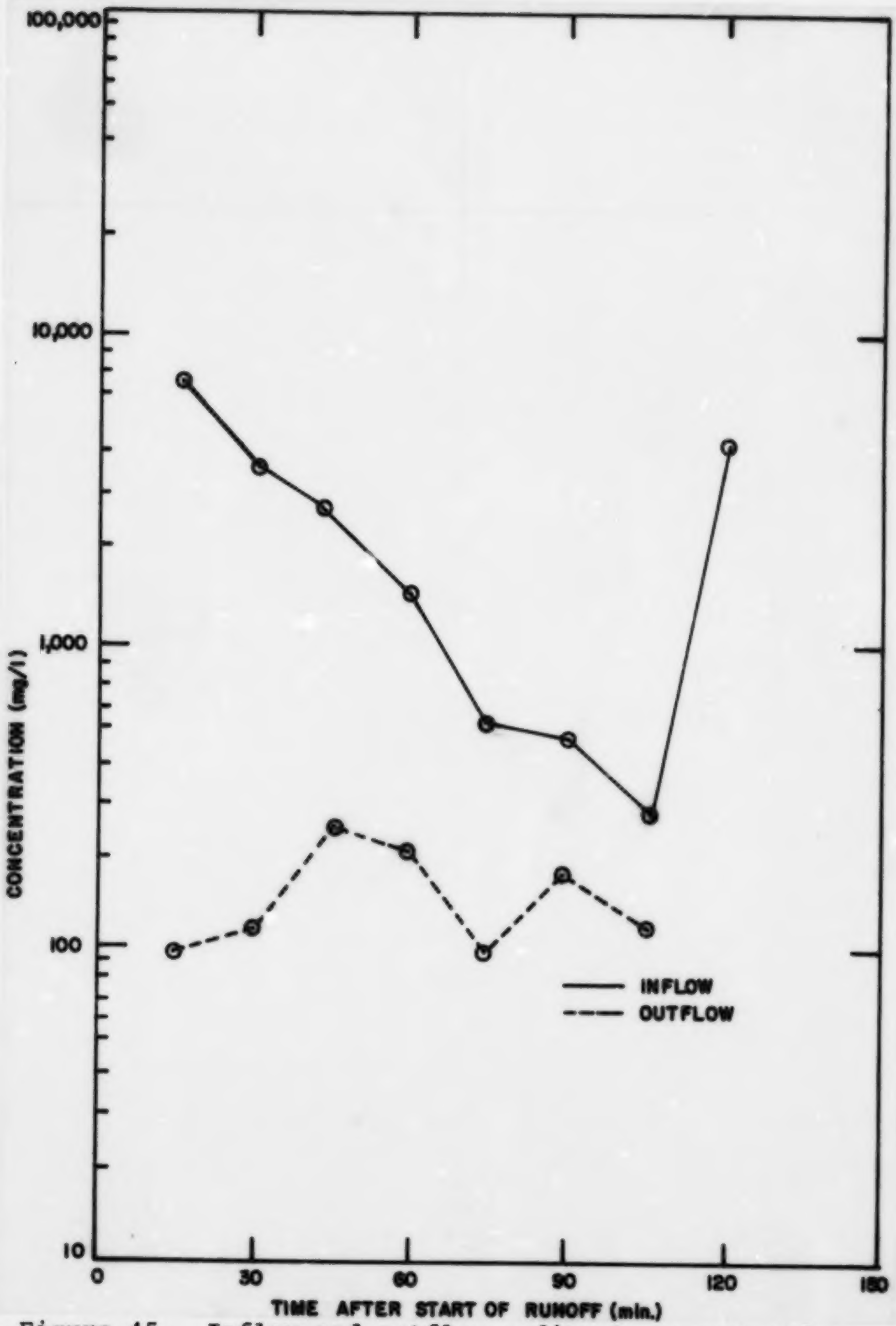


Figure 45. Inflow and outflow sediment concentrations for storm on April 11, 1980

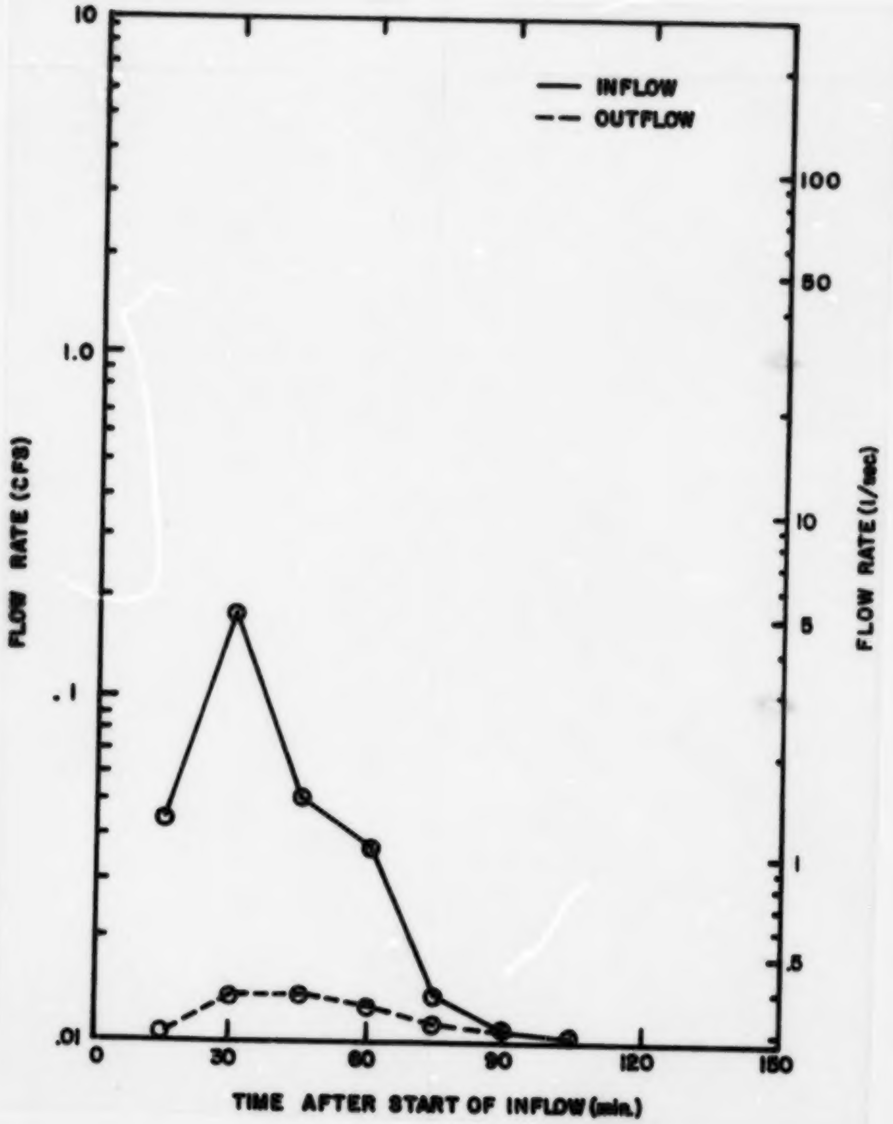


Figure 46. Inflow and outflow hydrograph for storm on April 11, 1980

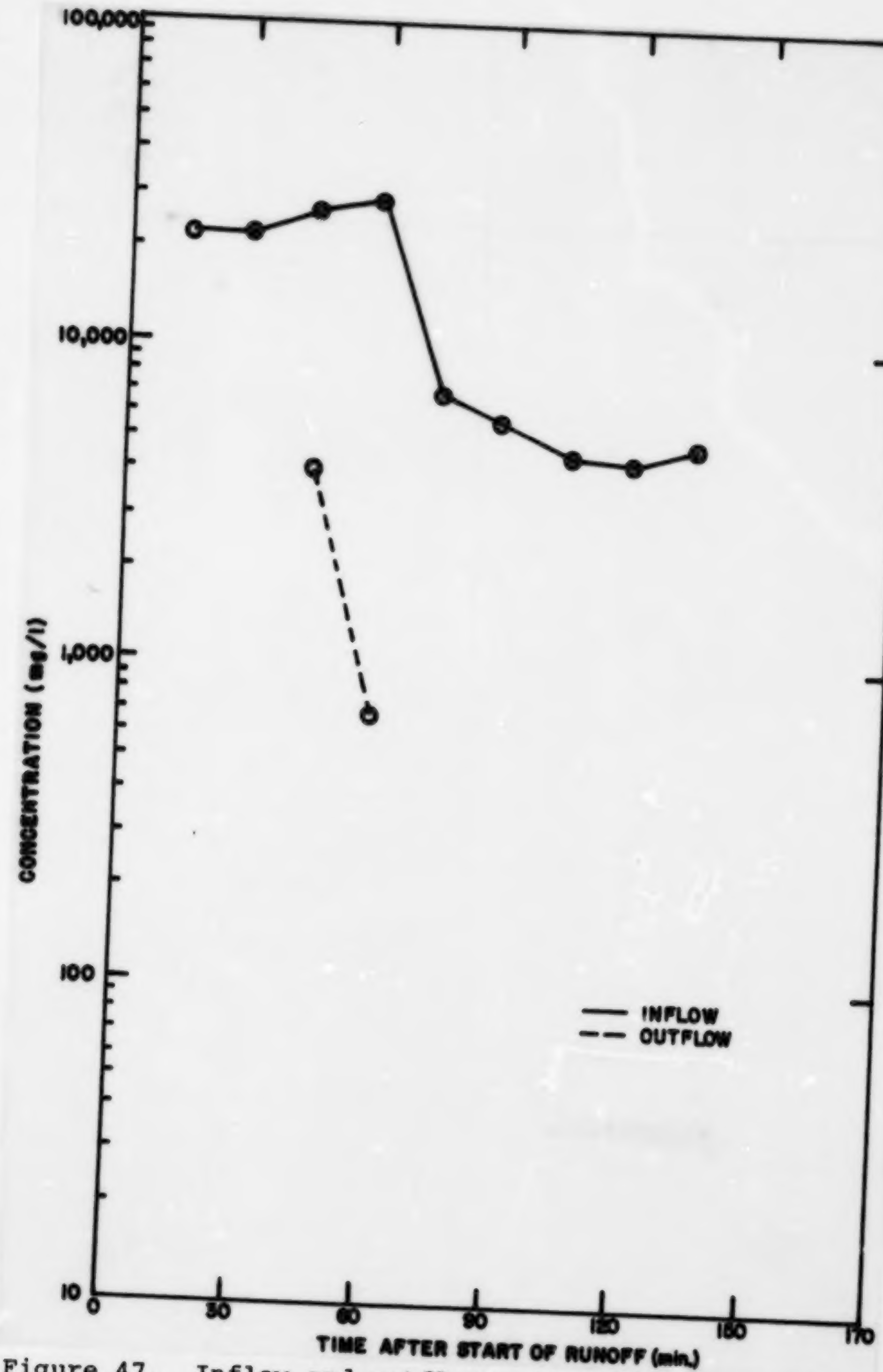


Figure 47. Inflow and outflow sediment concentrations for storm on May 17, 1980

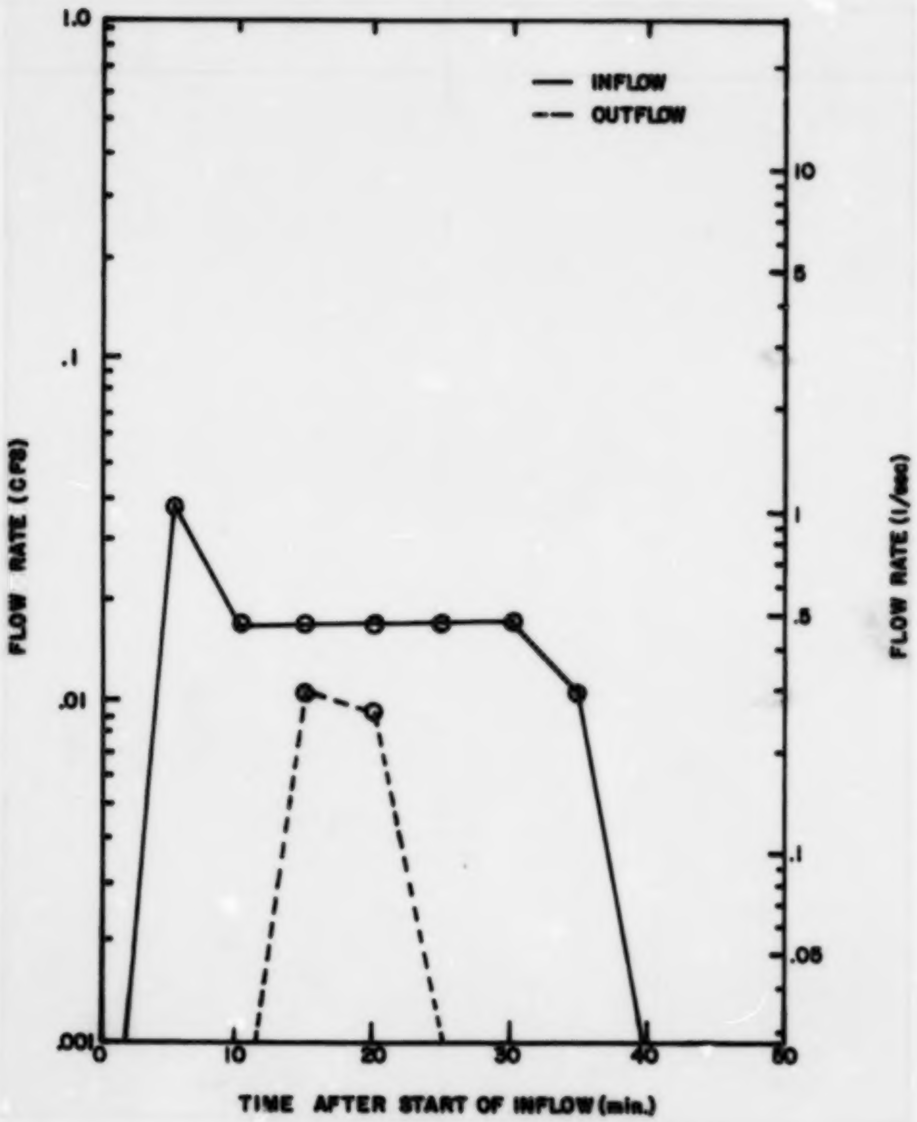


Figure 48. Inflow and outflow hydrograph
for storm on May 17, 1980

Storm of May 24, 1980 - The storm of May 24, 1980, was monitored by automatic equipment. The ink in the water stage recorder on the inflow H-flume smeared badly, making it impossible to determine an inflow hydrograph. Since outflow rates were very low, it may be assumed that inflow rates were also low.

The inflow and outflow concentrations are shown in Figure 49. Peak and average inflow concentrations were 67,000 and 37,402 mg/l. Peak and average effluent concentrations were 911 and 522 mg/l. The trap efficiency, based on inflow and outflow concentrations was 98.3 percent. Again, the vegetation adequately performed the task of filtering the sediment.

Storm of July 10, 1980 - The runoff from the July 10 storm was sampled by automatic equipment. Inflow and outflow hydrographs are shown in Figure 51. Peak inflow and outflow rates were 0.070 and 0.047 cfs. (1.98 and 1.33 l/sec). Infiltration accounted for 35 percent of the inflow.

Inflow and outflow concentrations are shown in Figure 50. Peak and average inflow concentrations were 3788 and 1420 mg/l. The trap efficiency, although flows were low, fell to 97.1 percent. The vegetation as of July 10, continued to do an excellent job of filtering sediment from the flow.

Storm of August 29, 1980 - The storm of August 29 was sampled by automatic equipment. The ink pens for the water stage recorders did not work properly, therefore only the concentrations can be calculated from the data. The concentrations are shown in Figure 52 and size distribution in Figure 53. The trapping efficiency of the vegetation was only 78.3 percent during this test, which was the lowest value for the filter to that date. By this time, however, considerable deposition had occurred throughout the filter.

The aggregate size distribution of the eroded sediment was such that 99 percent of the sediment was silt size or larger, indicating the filter continued to provide good trapping.

Storm of September 3, 1980 - The storm of September 3, 1980, was monitored by automatic equipment. According to the rainfall charts, over 9.0 cm of rain fell. This represents an intensity which has a return period of over 100 years (Haan and Barfield, 1978). An inspection of the site after the storm indicated that massive amounts of sediment had washed in during the storm, plugging the stilling wells and partially plugging the inlet to the pumping sampler. Sediment had also deposited in the middle of the filter with numerous boulders, four inches (10.2 cm) in diameter, washed

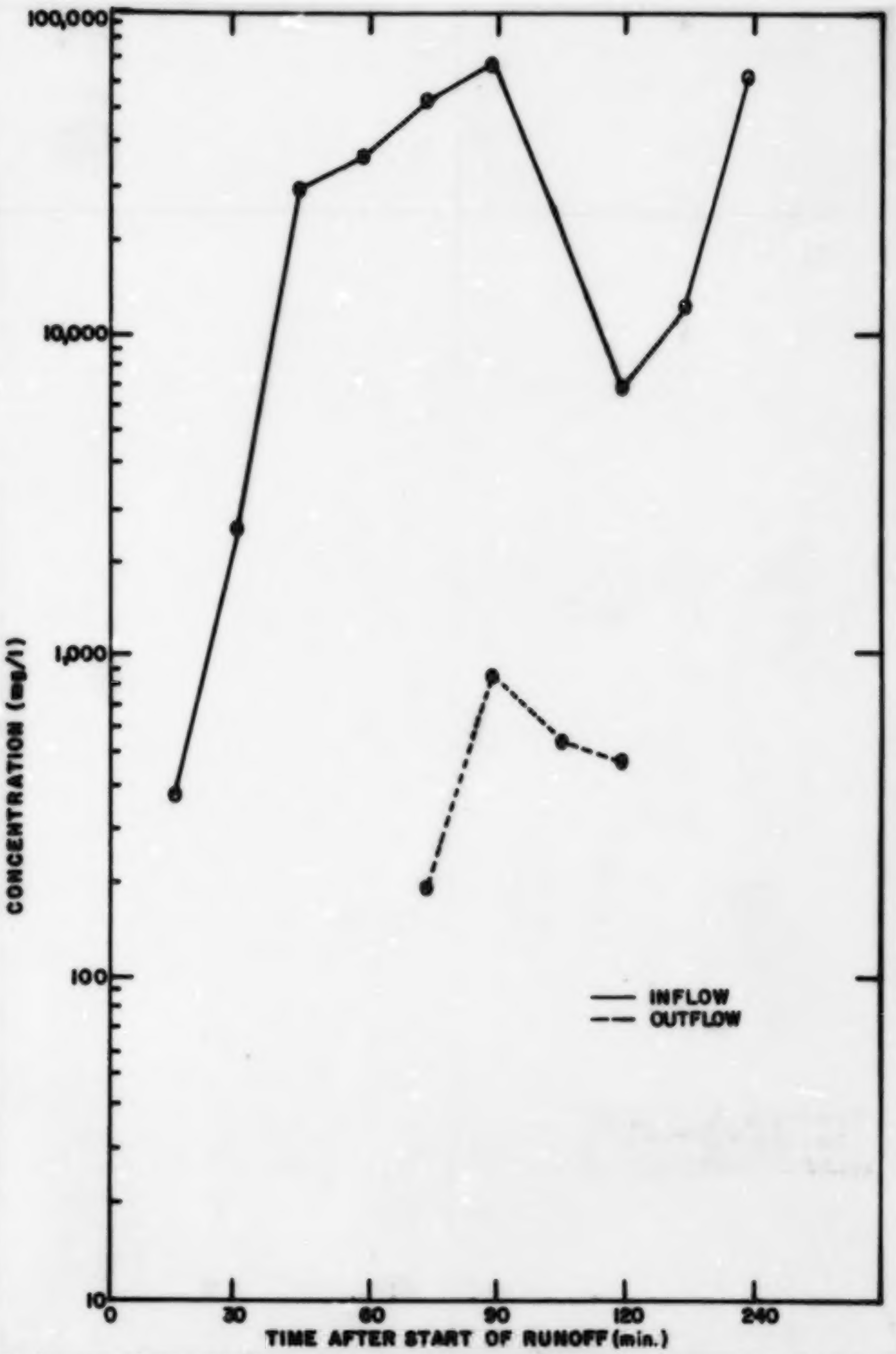


Figure 49. Inlow and outflow sediment concentrations for storm on May 24, 1980

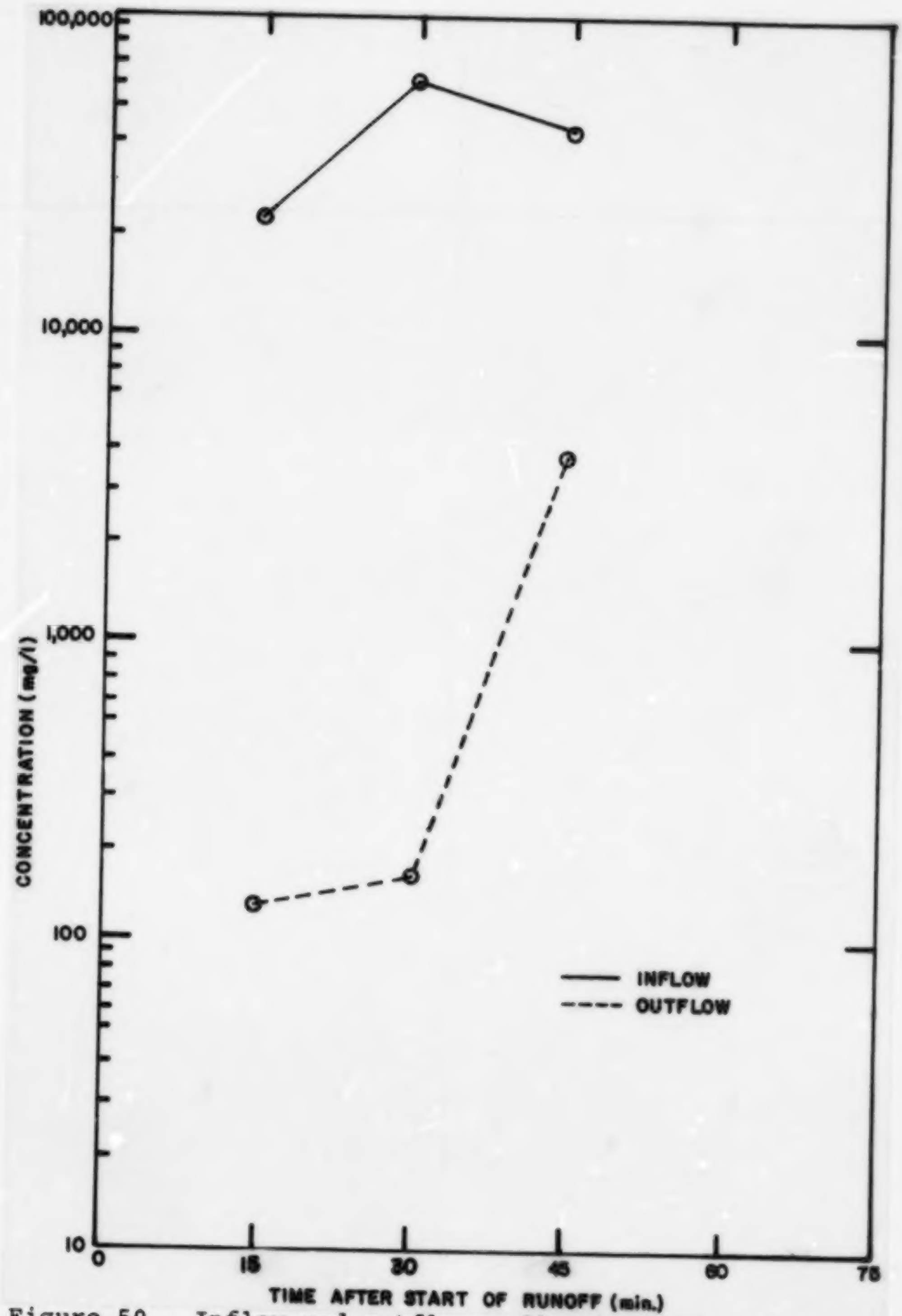


Figure 50. Inflow and outflow sediment concentrations for storm on July 10, 1980

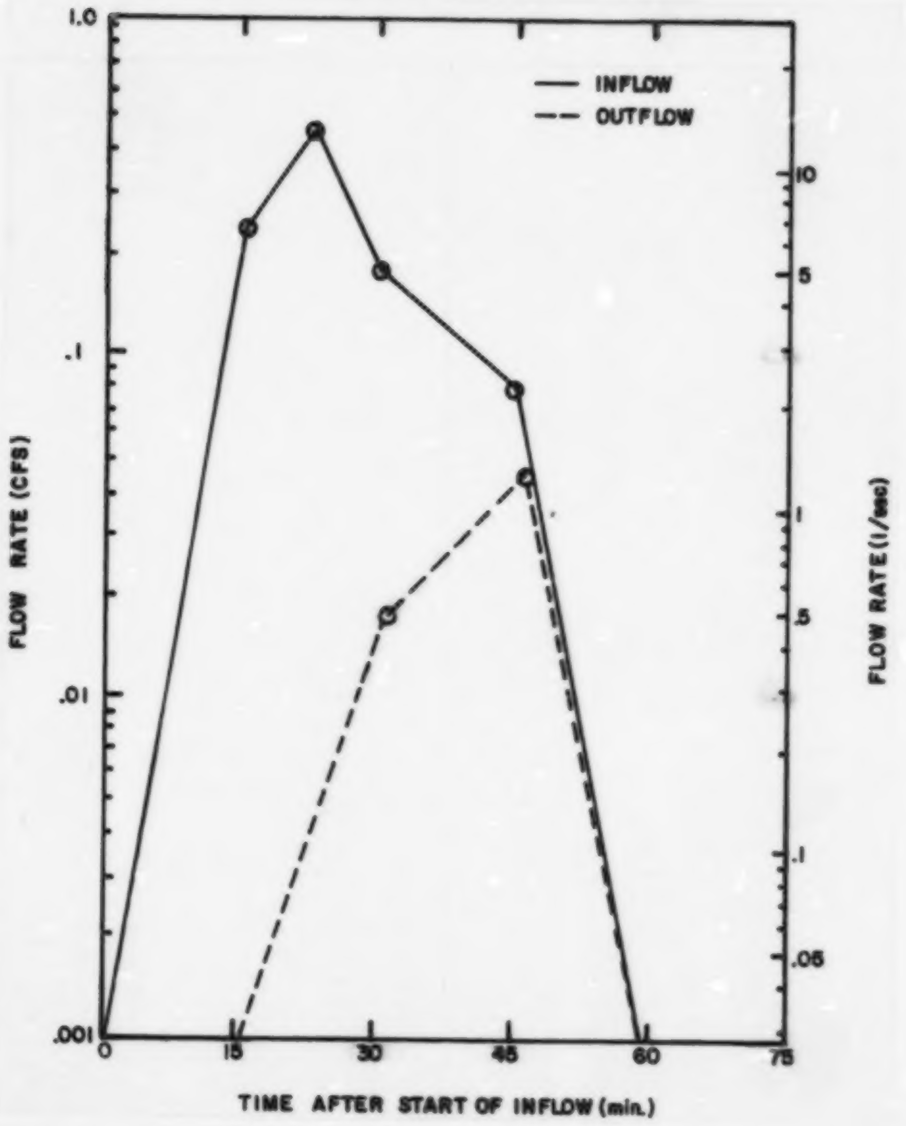


Figure 51. Inflow and outflow hydrograph for storm on July 10, 1980

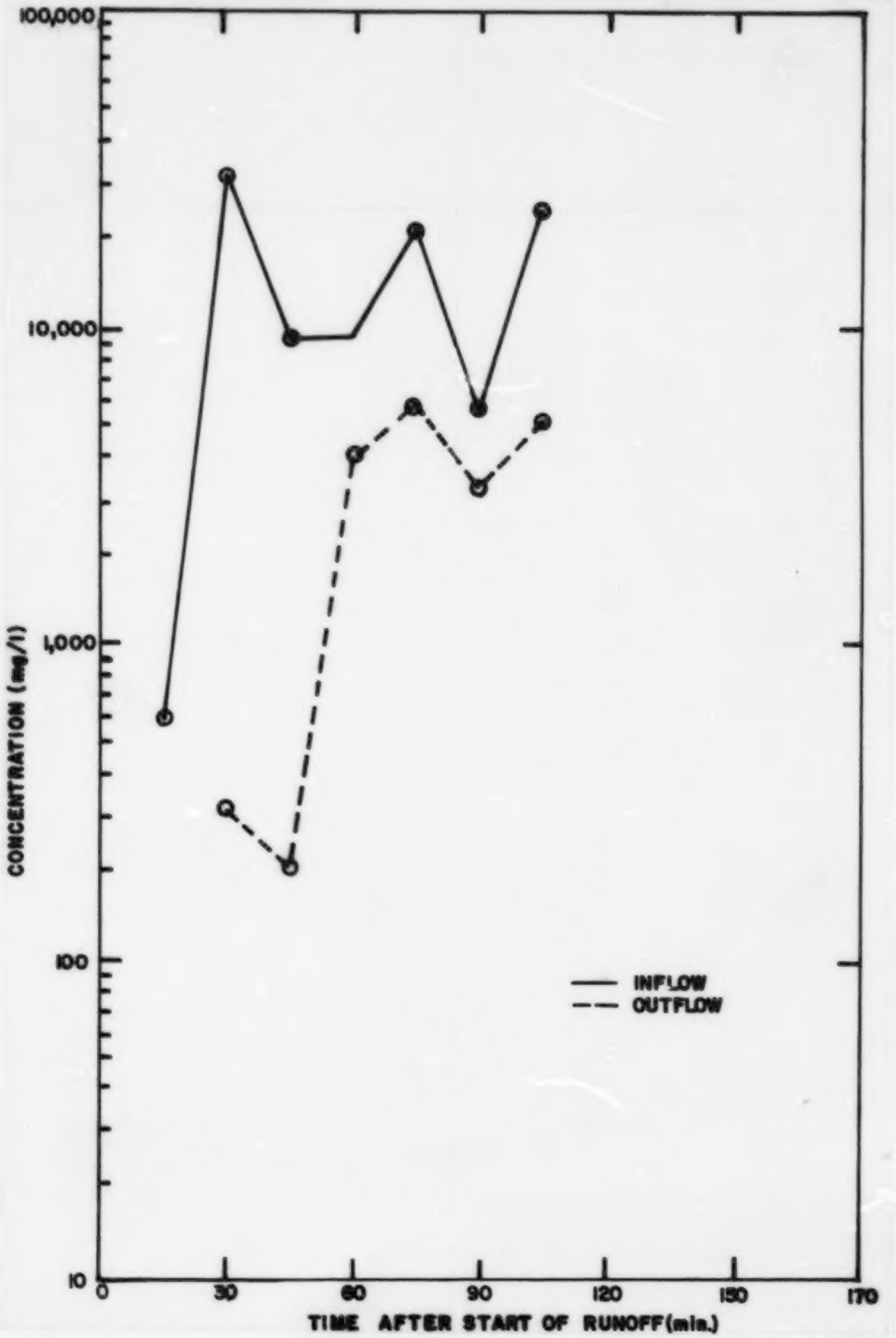


Figure 52. Inflow and outflow sediment concentrations for storm on August 29, 1980

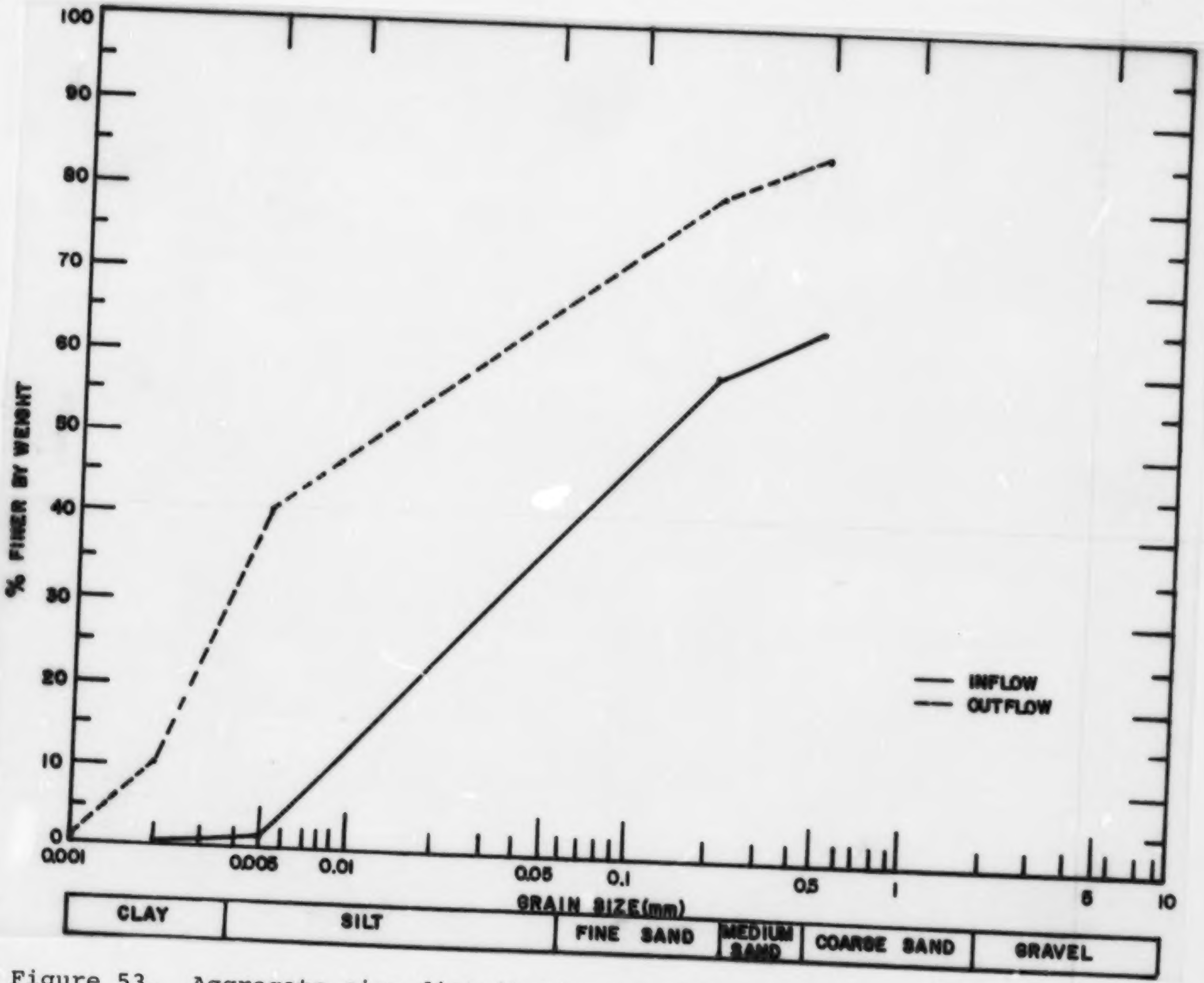


Figure 53. Aggregate size distribution of sediment for storm of August 29, 1980

as far as 40 feet (12.2m) into the plot.

Approximately 20 percent of the filter was completely inundated with sediment and large amounts were deposited in the vegetation.

These amounts of sediment would indicate a large concentration in the inflow, although a plot of the data as shown in Figure 54 does not substantiate this conclusion. Concentrations for this storm were lower than for most of the other small events. The aggregate size distribution is found in Figure 55.

STEADY STATE TESTS

Because of the difficulty in coordinating a trip to the site to coincide with runoff, it was decided to conduct at least one series of tests with an artificial water supply. By directing water over bare soils, sediment could be eroded and the sediment-laden water directed into the filter. A coal company water truck was made available for water supply and a test conducted on November 18, 1980. Prior to "dredging" sediment, clear water was directed onto the plots in order to satisfy some of the initial infiltration capacity. Water was directed onto the plots at approximately 0.14 cfs. (3.96 l/min.) for a 20 minute duration. At this point, the water truck had to be refilled.

Flow through was observed after four truckloads of clear water had been directed into the filter. At this time, sediment-laden flow was directed onto the plots and a total of three steady-state tests were conducted.

The results of the steady-state tests are shown in Figures 56 through 59. In each test, there was a large infiltration component, as evidenced in the difference in inflow and outflow hydrographs in Figure 59. This infiltration component is helpful in trapping the fines in the flow.

The inflow and outflow sediment concentration, along with percent trapped, are shown in Figure 56 through 58. The trapping percentages are quite high, considering that much of the filter had been inundated with sediment in the 100+ year storm that occurred over the site on September 3, 1980. Much of the trapped sediment was loose and readily available for erosion in subsequent storms.

SUMMARY

In summary, the vegetation (fescue) worked well as a filter for most of the year. The storms evaluated are

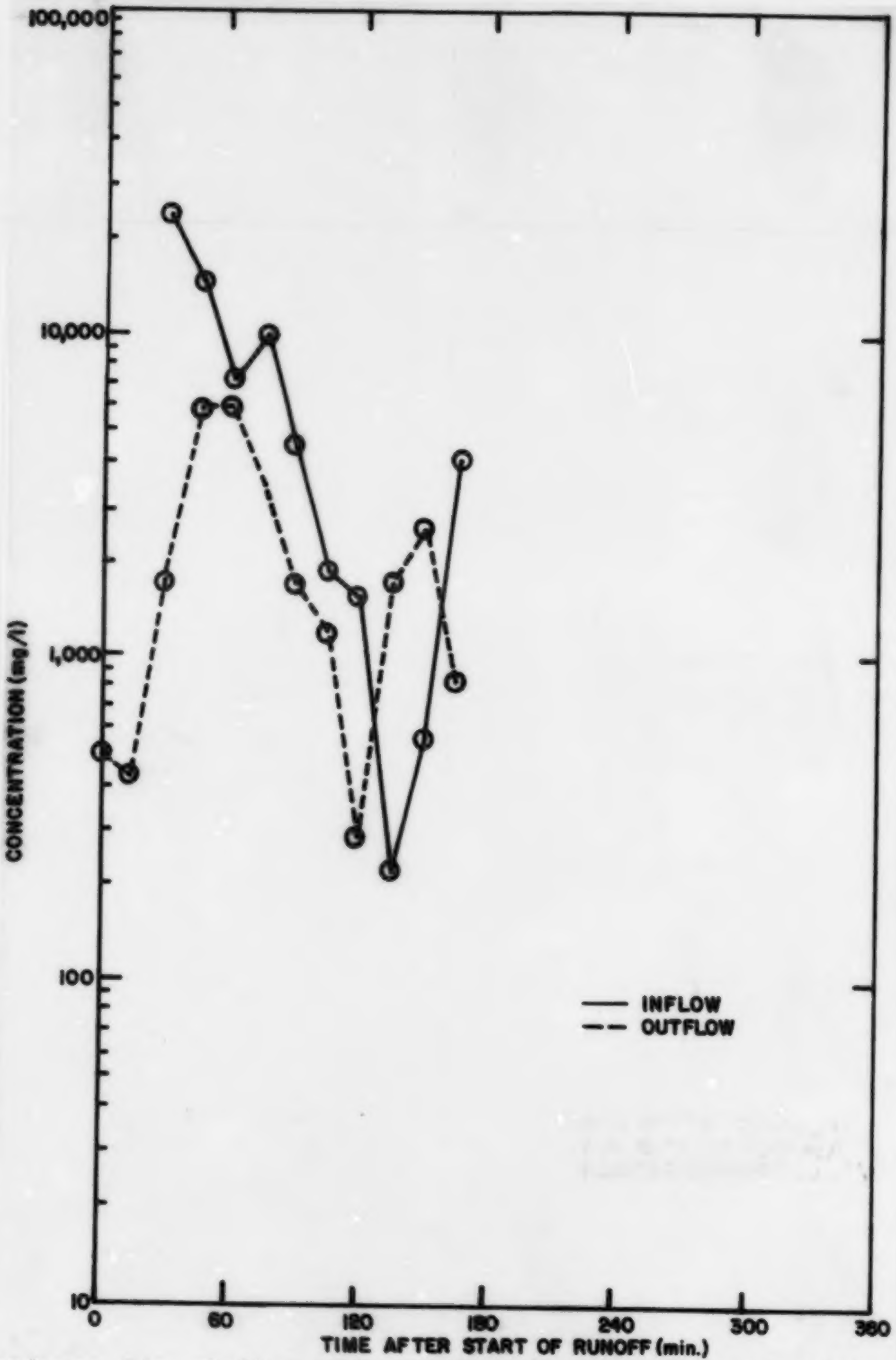


Figure 54. Inflow and outflow sediment concentrations for storm of September 3, 1980

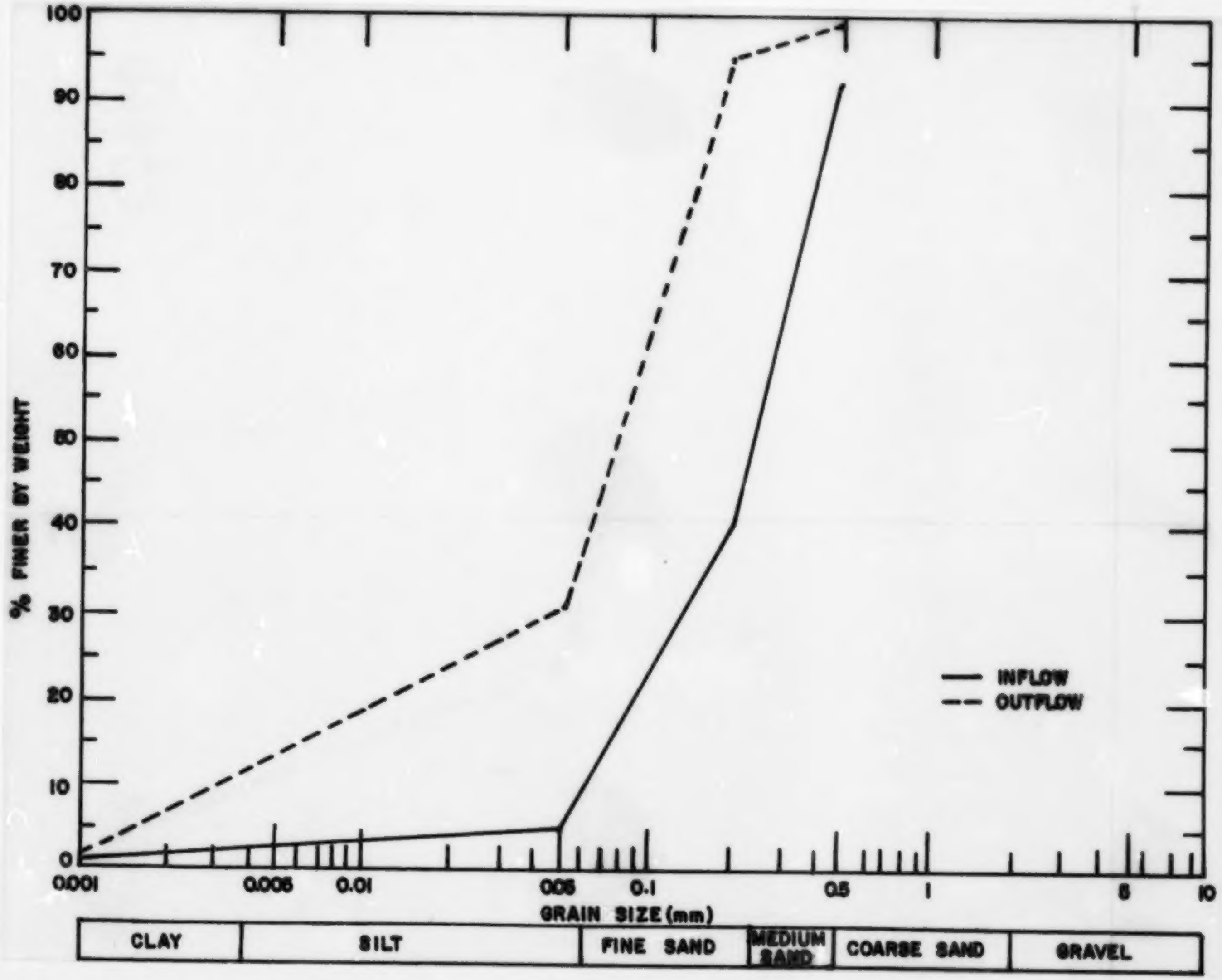


Figure 55. Aggregate size distribution of sediment for storm of September 3, 1980

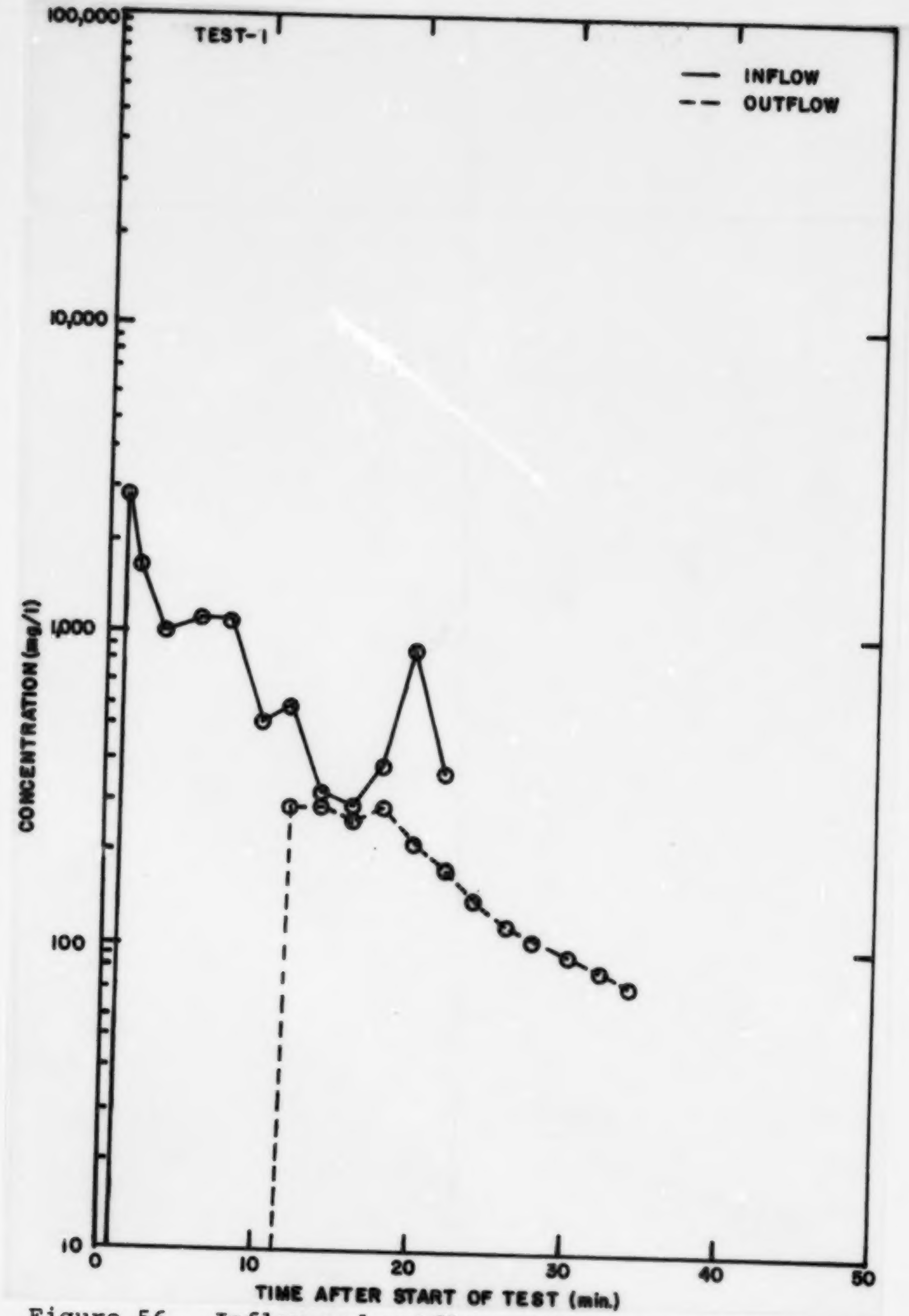


Figure 56. Inflow and outflow sediment concentrations for steady-state test 1

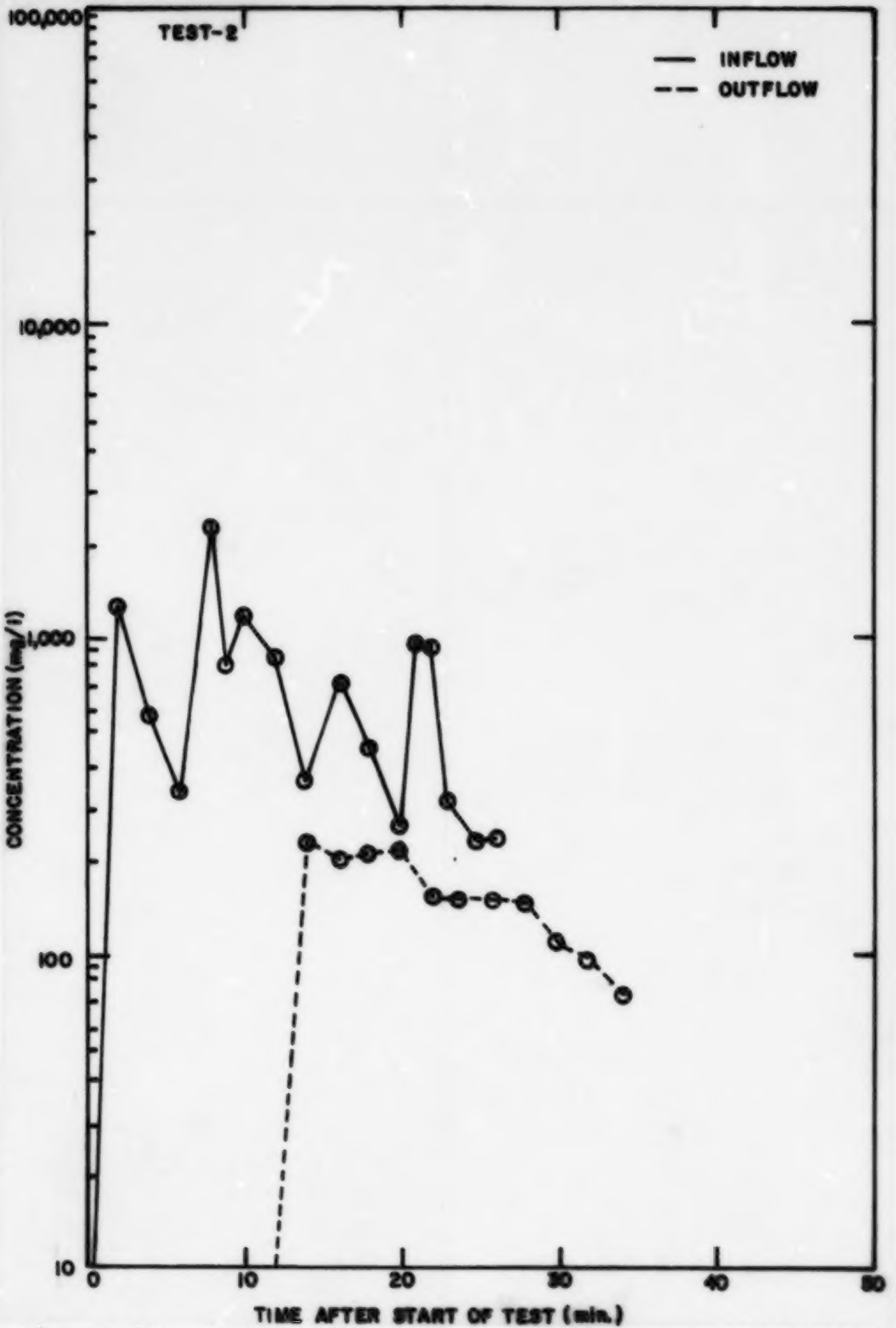


Figure 57. Inflow and outflow sediment concentrations for steady-state test 2

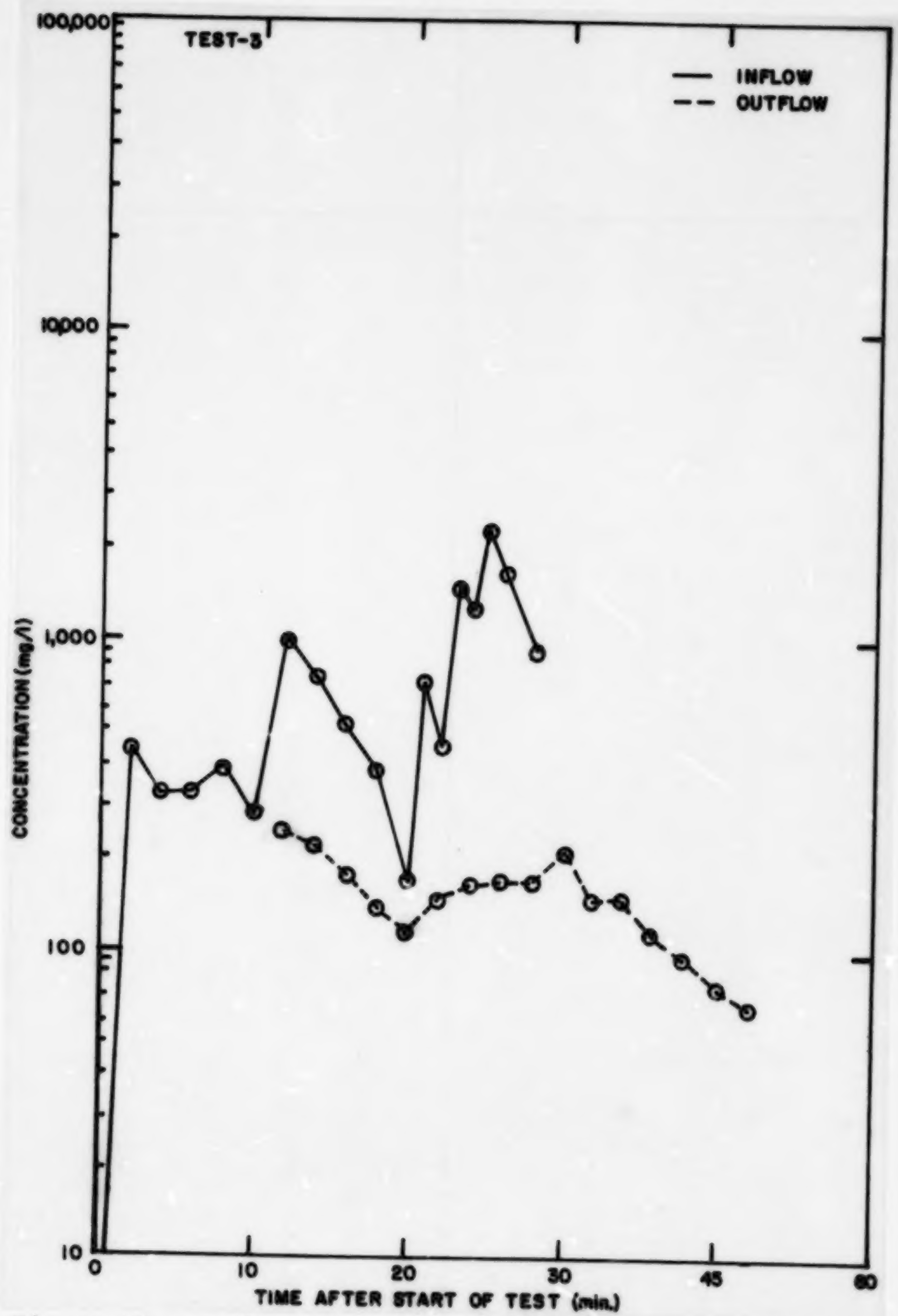


Figure 58. Inflow and outflow sediment concentrations for steady-state test 3

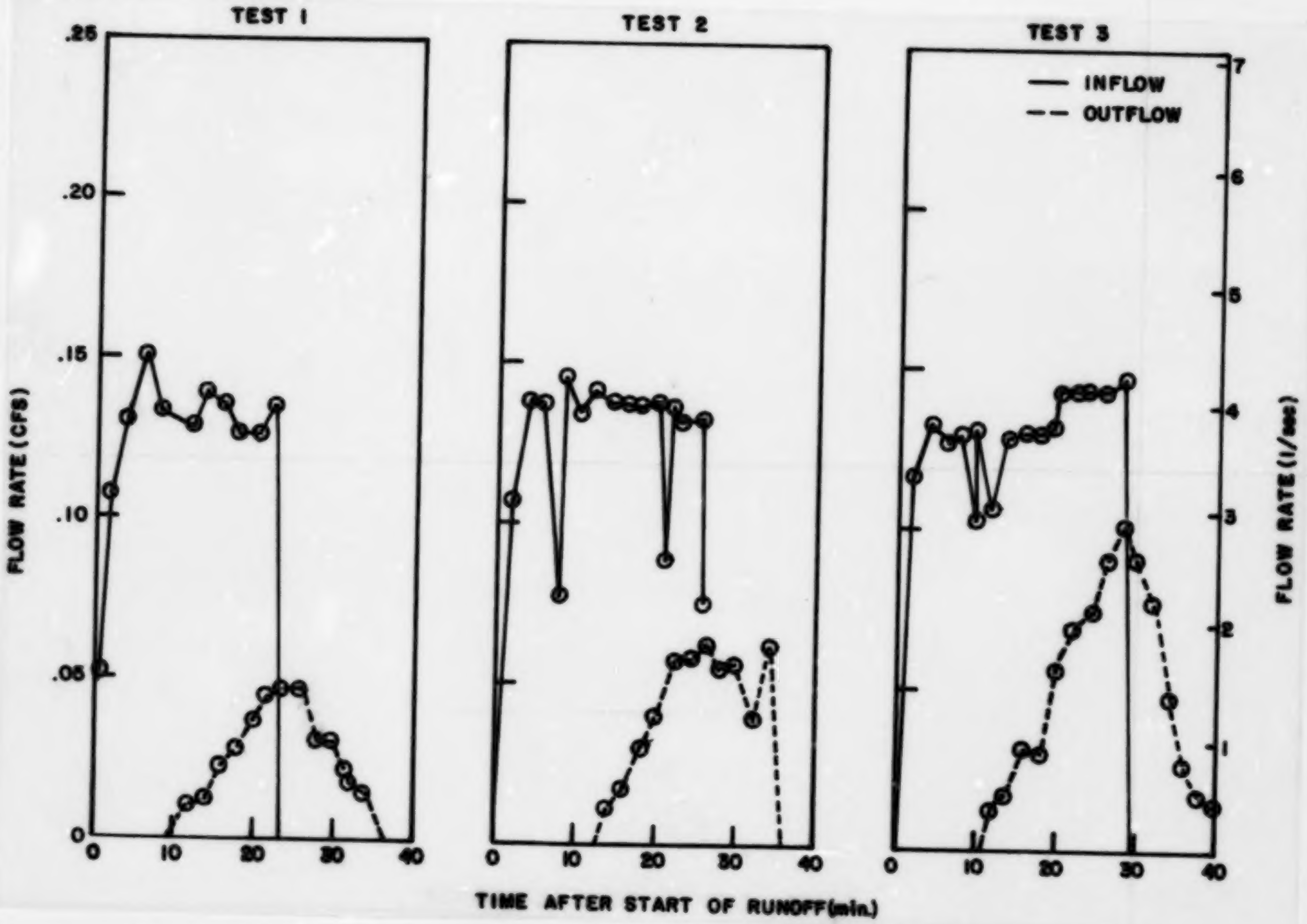


Figure 59. Inflow and outflow hydrographs for steady-state tests

summarized in Table 13. The 100+ year storm which occurred in September 3, 1980, caused significant deposition in the filter. Subsequent tests showed a decrease in trapping efficiency. The trapping efficiency in storms early in the monitoring period were very high, (95-100 percent), but toward the end of the period trapping efficiencies had decreased approximately 75 percent.

The size distribution of the eroded sediment was such that most of the aggregates and primacy particles were silt size or larger.

TABLE 13. SUMMARY OF STORMS SAMPLED

Date of Storm	Peak Inflow Rate L/sec.	Peak Outflow Rate L/sec.	Volume Inflow	Volume Outflow	Percent Infiltrated %	Peak Inflow Conc. mg/l	Peak Outflow Conc. mg/l	Mass Sediment Inflow Kg	Mass Sediment Outflow Kg	Percent Sediment Trapped %	Total Rainfall cm
January 11, 1980	—	—	—	—	—	8,939	1,607	—	—	92.5	2.2
April 3, 1980	2.1	.85	2,745	1,245	54.6	70,100	2,400	85.00	.35	>99	2.6
April 11, 1980	4.8	.36	8,093	1,670	79.3	6,380	240	39	.6	>99	2.8
May 17, 1980	1.1	.34	3,623	538	85.2	30,148	4,651	54	1.6	97.1	4.1
May 24, 1980	—	—	—	—	—	67,200	911	—	—	98.3	3.8
July 10, 1980	12.7	1.33	2,575	1,669	35.1	62,487	3,788	441	5	>99	1.2
August 29, 1980	—	—	—	—	—	30,200	5,600	—	—	78.3	2.3
September 3, 1980 [2]	1.9	—	—	—	—	24,900	5,900	—	—	70.4	9.0
October 18, 1980 [3]											
Test 1	4.24	1.36	—	—	—	28,692	3,180	—	—	—	—
Test 2	4.02	1.93	—	—	—	22,636	2,324	—	—	—	—
Test 3	4.13	2.91	—	—	—	24,030	2,460	—	—	—	—

[1] Not all storms were sampled since new equipment completely malfunctioned.
[2] Numbers probably suspect due to the magnitude of the event. Equipment failure resulted.
[3] Runoff and sediment generated by spraying water from a water truck onto a disturbed area.

SECTION 8

COMPUTER MODEL VALIDATION

INTRODUCTION

One of the desired objectives of the project was further experimental evaluation of the Kentucky Grass Filter Model described in Section 3. Data from the storms in which only automatic samplers were used proved insufficient for model evaluation, so it was decided to use only the hand sampled data sets. The data selected came from the April 3, 1980 data set and the steady-state data sets. The parameter evaluated was the ability of the model to predict trapping efficiency.

As used in this section, trapping efficiency is calculated by:

$$T_r = \frac{C_{i,j}q_{i,j} - C_{o,j}q_{o,j}}{C_{i,j}q_{i,j}}$$

Where $C_{i,j}$ and $C_{o,j}$ refer to the inflow and outflow concentration of the j, the elements q_{ij} and q_{oj} refer to the inflow and outflow rate of the j. The element T_{rj} is the trapping efficiency the the j element.

In order to make predictions, it is necessary to have the inputs required for the model. The inputs not directly measured as a part of the project were taken from Hayes et al (1981). A summary of the data inputs used is given in Table 14.

RESULTS

April 3, 1980 Storm - Predicted and observed trapping efficiencies for the April 3 data set are shown in Figure 60. The agreement is excellent. At this time, the filter was essentially free of sediment deposited in the vegetation, therefore, the soil surface tended to serve as an absorbing barrier, trapping all particles which struck it.

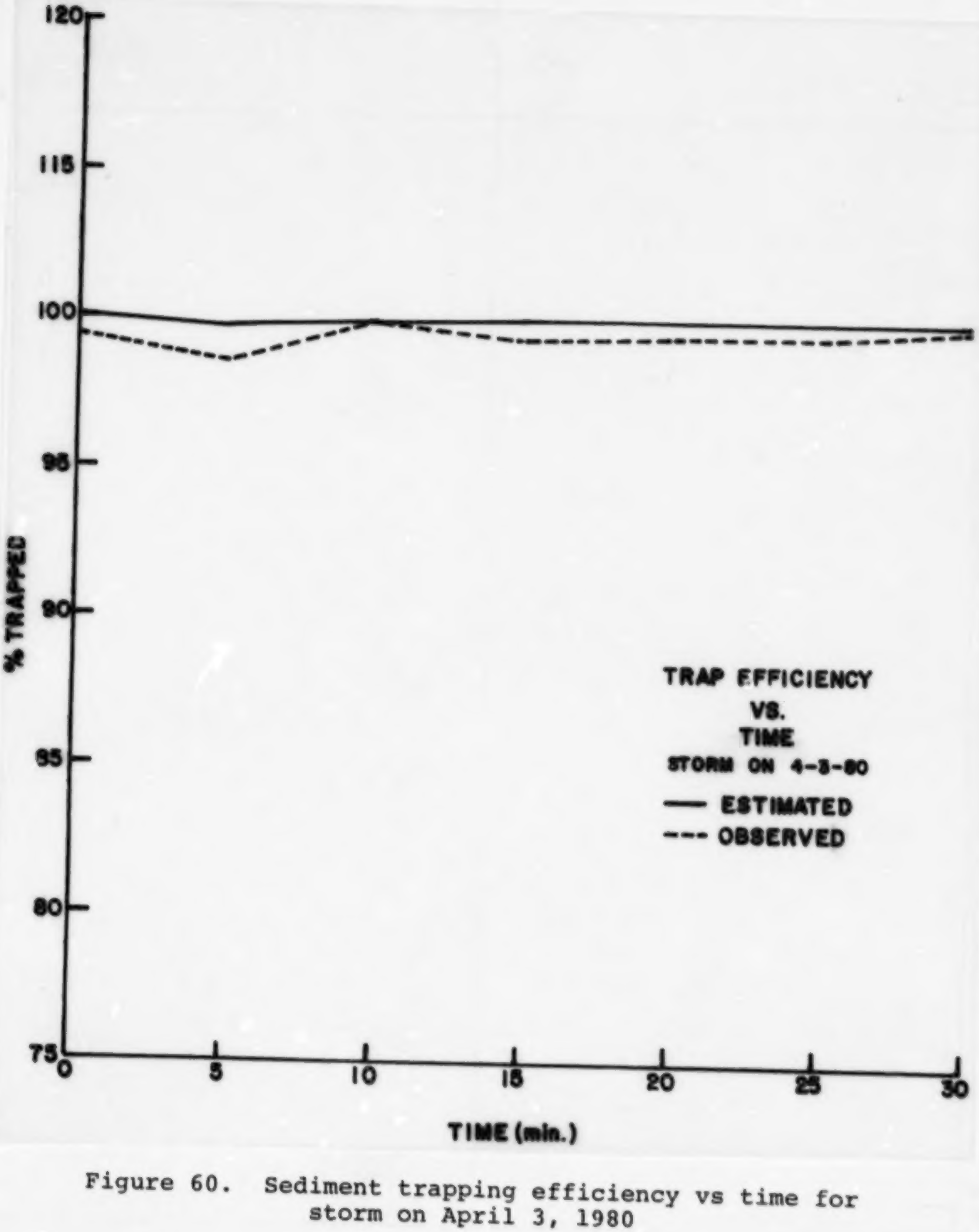


Figure 60. Sediment trapping efficiency vs time for storm on April 3, 1980

TABLE 14. INPUTS NECESSARY FOR RUNNING THE KENTUCKY GRASS FILTER MODEL

Filter Length = 41 meters (measured)

Filter Width = 21 meters

Filter Slope = 17 percent (measured)

Spacing = 1.43 - 1.70 cm 1/

Grass Diameter = .128 cm 1/

Manning's n - 0.161

Inflow rate (specific for each test)

Inflow sediment concentration (specific for each test)

Inflow size distribution (specific for each test)

1/ From Hayes et al (1981)

Steady-State Tests

Predicted and observed trapping efficiencies are shown in Figure 61 through 63. The agreement is poor. Most of the lack of agreement can be attributed to the massive amounts of sediment deposited in the filter during the September 3 storm. By visual inspection, one could observe that most of the deposition occurred over the center sections of the filter and less amounts in the outer edges. This unequal deposition caused flow patterns to be irregular and unpredictable. If the deposition had been uniform across the slope, it could have been accounted for in the model by adjusting the slope length.

One would not normally expect the sediment to deposit in the uneven manner described in the previous paragraph. In the storm leading up to September 3, deposition was uniform across the slopes. However, in the storm of September 3, flows were so large that the H-flume acted as a jet, causing the flow to "gush" over the flow dividers out onto the filter. From there, the flow and deposition spread radically in all directions.

It should be pointed out that the potential exists for making the predictions fit the observed data by optimizing the parameters. This was not done, since it was believed that the optimization served no useful purpose.

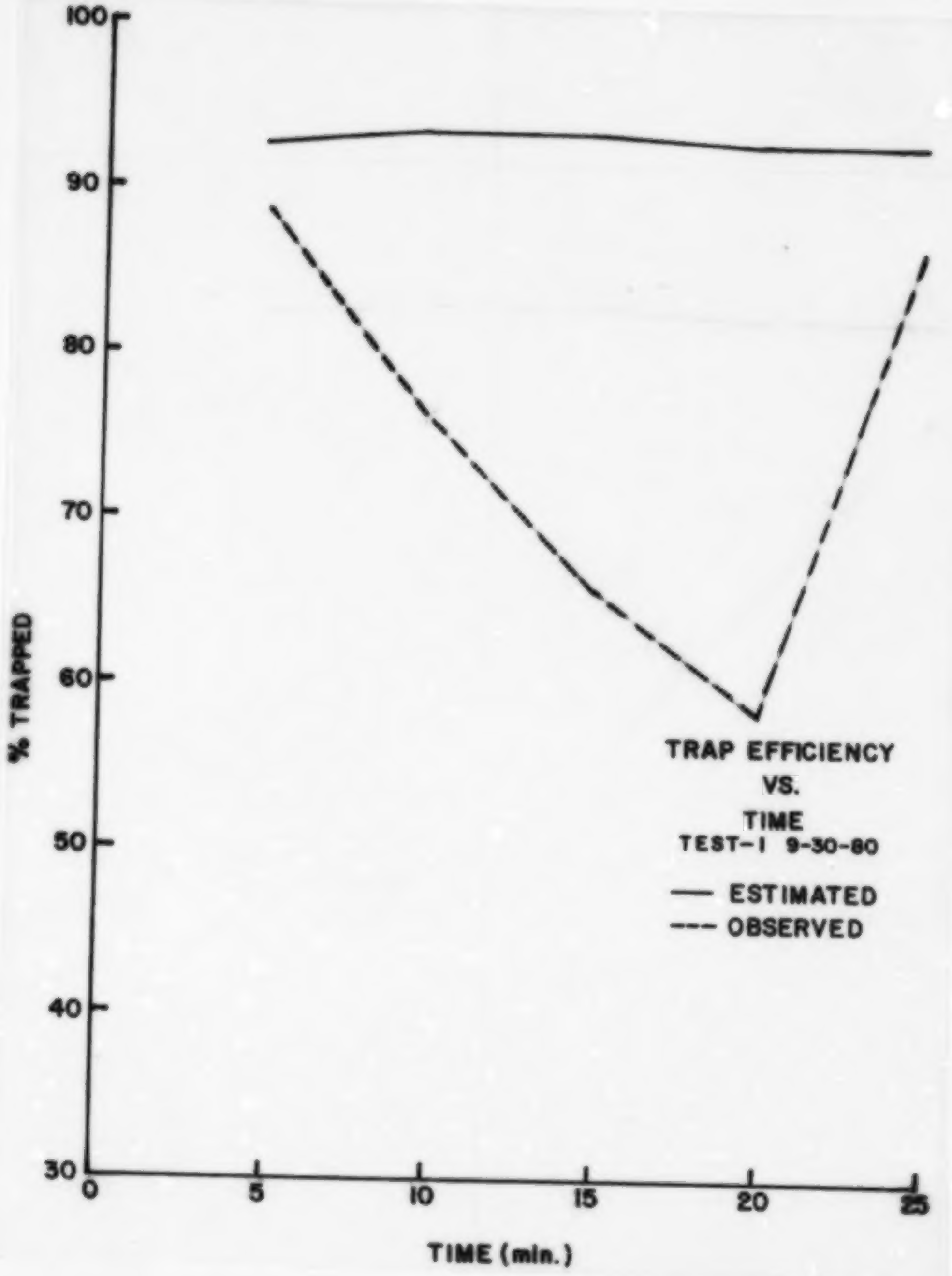


Figure 61. Sediment trapping efficiency vs time for test 1

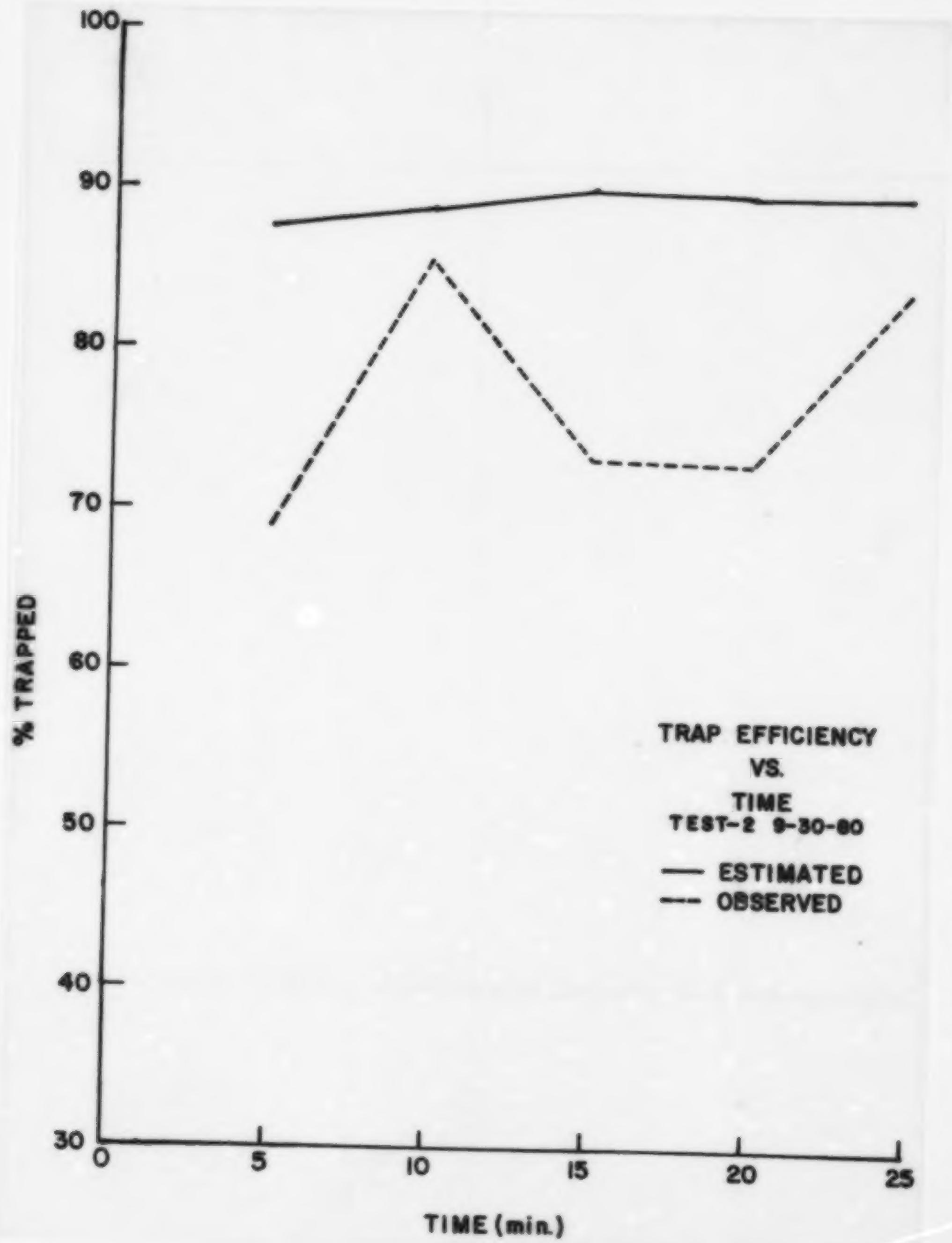


Figure 62. Sediment trapping effiiency vs time for test 2

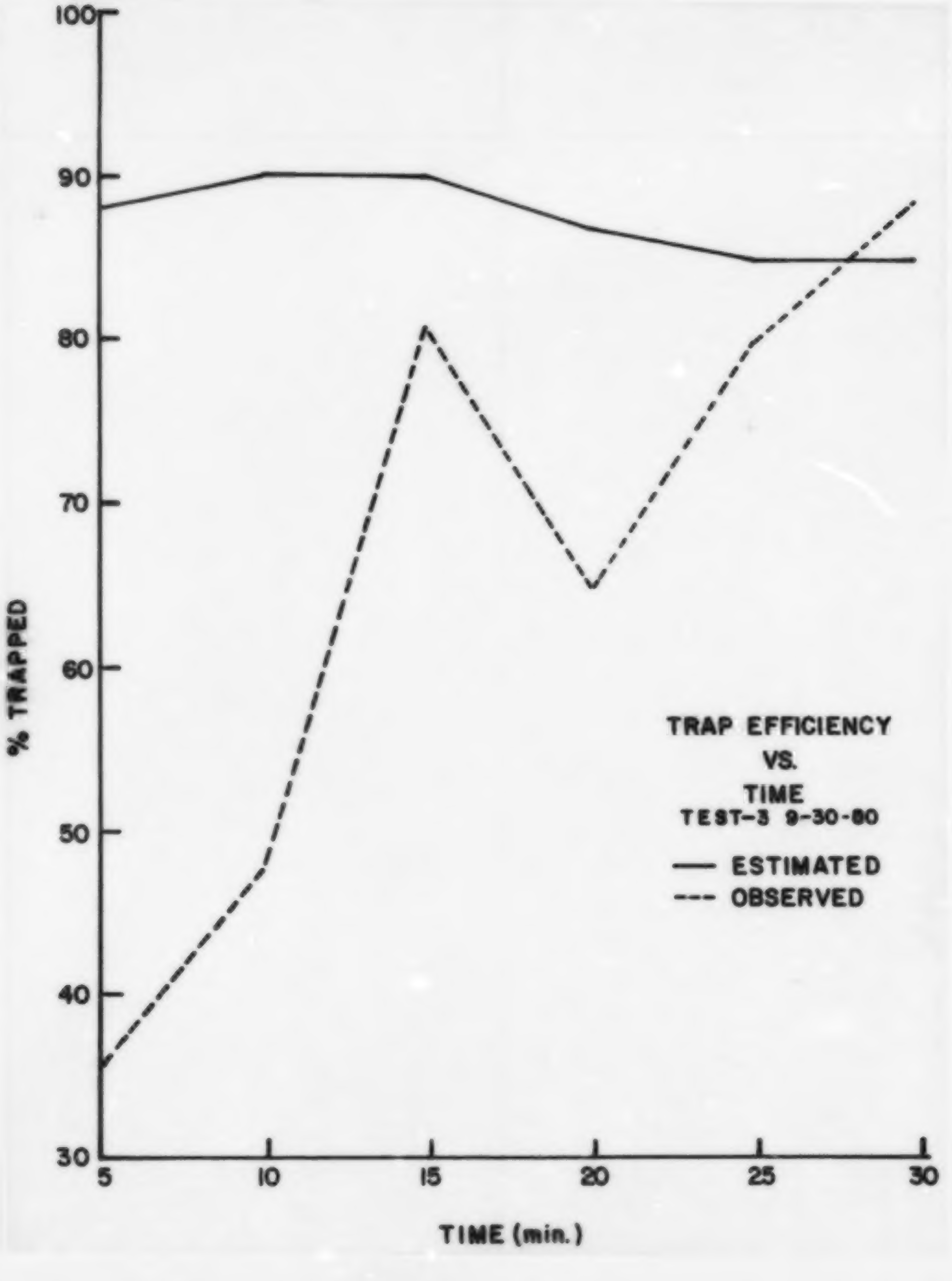


Figure 63. Sediment trapping efficiency vs time for test 3

Conclusions from Model Evaluation

In conclusion, the Kentucky Grass Filter Model did an excellent job of predicting the trapping efficiency in the storm data. For the steady-state tests, the agreement was fair to poor. The probable reason for this lack of agreement was the poor condition of the filter resulting from the large amounts of deposition which occurred during a previous extreme event.

One can conclude from these tests, and previous studies cited in Chapter 3 that the Kentucky Grass Filter Model may be used to adequately predict trapping efficiency for filters that are in good condition.

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METRIC CONVERSIONS

For use in the Appendices as well as the body of the report.

TO CONVERT	TO	MULTIPLY BY
Acres	Hectares	4.047×10^{-1}
Cubic Feet	Cubic Meters	2.832×10^{-2}
Feet	Meters	2.048×10^{-1}
Miles (Statute)	Kilometers	1.609
Inches	Centimeters	2.540
Pounds	Kilograms	4.536×10^{-1}
Tons	Kilograms	907.2

APPENDIX A

COMPUTATION PROCEDURES FOR RUNOFF HYDROGRAPHS

A. CALCULATION OF RUNOFF HYDROGRAPH

1. Area (See plot plan)

TABLE A1. AREA

Segment	Acreage	ft^2	mi^2
AB	.3291		
BC	.3129		
CD	.4709		
TOTAL	1.1129	48477	.0017

2. Curve Number

Select: Hydrologic Soil Group C (Haan and Barfield, 1978, Table 2.19, Pg. 67)

Soils with slow infiltration rate when wet

Curve No. = 88 (Haan and Barfield, 1978, Table 2.20, Pg. 63)

3. Runoff Volume

TABLE A2. RUNOFF VOLUME

Return Period (Yr.)	24 Hour Precip. (in.) (Haan & Barfield, 1978, Appendix 2A-2, pg. 107)	Runoff (in.) (Haan & Barfield, Fig. 2.26, pg. 70)
2	3.1	1.8
5	3.9	2.7
10	4.5	3.2

4. Time of Concentration

Average slope = 95 ft./279 ft. = 34%

Velocity = 1.5 ft./sec. (Haan and Barfield, 1978, Figure 2.34, pg. 32, Between forest and trash fallow conditions)

Distance = 230 ft.

T_c = 230 ft./1.5 ft./sec. = 2.55 min.

Use T_c = .1 hr. minimum value

5. Hydrographs (Soil Conservation Service, 1975, pg. 5,7)

T_c = 0.1 hr.

T_t = 0.04 hr. $\simeq$ 0

TABLE A3. HYDROGRAPHS

Time	Ordinate (CSM/in)	Area (mi^2)	Hydrograph Storm 2 yr. 1.8 in.	Hydrograph Storm 5 yr. 2.7 in.	Hydrograph Storm 10 yr. 3.2 in.
11.0	24	.0017	0.07	0.11	0.13
11.5	51	"	0.16	0.23	0.28
11.7	299	"	0.91	1.37	1.63
11.8	991	"	3.03	4.55	5.39
11.9	746	"	2.28	3.42	4.06
12.0	477	"	1.46	2.19	2.59
12.1	233	"	0.71	1.07	1.27
12.2	152	"	0.47	0.70	0.33
12.3	132	"	0.40	0.61	0.72
12.4	121	"	0.37	0.56	0.66
12.5	111	"	0.34	0.51	0.66
12.6	85	"	0.26	0.39	0.46
12.7	74	"	0.23	0.34	0.40
12.8	70	"	0.21	0.32	0.38
12.9	68	"	0.21	0.31	0.37
13.0	65	"	0.20	0.30	0.35
13.2	52	"			
13.5	38	"			
14.0	39	"	0.12	0.18	0.21
15.0	29	"	0.09	0.13	0.16

B. COMPUTATION OF SEDIMENT YIELD TO FILTER

1. Site Data

TABLE B1. SITE DATA

Segment	Slope Length λ (ft)	Slope %	Ground Cover % (estimate)	Drainage Area (Ac) (From topo Map)	Width (ft)
AB	65	23.4	40	.3291	190
BC	80	57.4	40	.3129	180
CD	155	26.8	70	.4709	165
DE	206	15.8	70		
TOTAL				1.1129Ac 48,477 ft^2	

2. Return Period Values of Precipitation and Erosion Index R

TABLE B2. RETURN PERIOD VALUES OF PRECIPITATION AND EROSION INDEX R

Return Period Years	24 Hr. Precip. (in.) (Haan & Barfield, 1978, pg. 123)	Single Storm Rainfall Factor -R- (Haan & Barfield, 1978, pg. 188)
1	--	28
2	3.1	46
5	3.9	80
10	4.5	114

3. Size Distribution of Eroded Sediment

4. Determination of Factors in Deposition Modified USLE

(a). $r = 14 \times 10^{-8}$ (Haan and Barfield, 1978, Fig. 5.19, pg. 210)

Assume: Runoff potential for bare fallow soil, mod - high

(b). R = 46 for 2 yr. storm (Using data for Lexington, Kentucky)

30 for 5 yr. storm

114 for 10 yr. storm

(c). $T = 3.7 \times 10^5 \left(\frac{lb - sec}{ft2}\right)$ (Using $D_{50} = 0.1$ from Fig. 1A-1)

(d). $\lambda_{AB} = 65'$ λ_{AB} (cumulative) = 65' (From Table 1)

$\lambda_{BC} = 80'$ λ_{AC} " = 145'

$\lambda_{CD} = 155'$ λ_{AD} " = 300'

$\lambda_{DE} = 206'$ λ_{AE} " = 506'

(e). S' for segment AB, $\sin \theta = .228$

BC, " = .498

CD, " = .259

DE, " = .156

(f). B = 1.7 (Using particle diameter of 0.1 mm & SG = 2.65)

(g). (Haan and Barfield, 1978, Table 5.8, pg. 209)

C_{ro}	C_{ro}	Segment
	.56	AB
	.56	BC
	.50	CD
	.50	DE

(h). Use Medium Runoff Rates (Haan and Barfield, 1978, Fig. 5.20b)

Particle D = 0.1 mm

SG = 2.00

For Segment AB & BC
Assume treatment is poor grass with rough surface depression
Velocity Ratio = 0.85

For Segment CD & DE
Assume treatment is good grass
Velocity Ratio = 0.50

TABLE B3. SLOPE SEGMENT DATA

Segment	Velocity Ratio	% Slope	Relative Transport Capacity (Table 5.9)		Ratio of Relative Transport to Transport of Medium Sized Aggregates, SG = 2.65 (Fig.5.20)		C_T
AB	0.85	23.4	.55	x	.96	=	.53
BC	0.85	57.4	.65	x	.98	=	.64
CD	0.50	26.8	.06	x	.62	=	.04
DE	0.50	15.8	.06	x	.65	=	.04

(i). K_j From Size Distribution Curve Figure 1A-1

% Sand (>.1mm)	50
% Very Fine Sand () .1-.062mm)	16
% Silt (.062-.004mm)	29
% Clay (<.004mm)	5
	100
% Organic Matter	0%
% Silt = % VFS	45%

K = 0.38
(Haan and Barfield, 1978, Fig. 5.90, pg. 189)

(j). $CP_j = C_s \times C_r \times C_o$

(Haan and Barfield, 1978, Table 5.5, Factor for Mechanically Prepared Woodland Sites)

Segment	% Cover	Disced, Raked, Bedded Weed Cover WC Soil Condition Poor		Surface Roughness Factor	C_s
AB	40	.19	x	.65	.11
BC	40	.19	x	.65	.11

(Haan and Barfield, 1978, Table 5.6, Factor for Permanent Pasture)

	C_s Appreciable Brush (2m fall ht) Canopy Cover Cover - W	
CD	70	.06
DE	70	.06

Summary

Segment	CP_j
AB	.11
BC	.11
CD	.06
DE	.06

(k). $$S_m = \frac{.043 + 30x_j + 430x_j^2}{6.613}$$

(Haan and Barfield, 1978, eqn. 5.9, p. 193)

$x = \tan\theta \simeq$ % slope/100

Segment	x	S_j
AB	.234	2.8
BC	.574	11.4
CD	.268	4.0
DE	.158	2.0

(l). m exponent dependent on slope

for slopes $\geq 5\%$

$m = 0.5$ (Haan and Barfield, 1978, pg. 191)

(m). Tabulation of Factors

TABLE B4. TABULATION OF FACTORS

TABLE B4. TABULATION OF FACTORS

Slope Segment	r	R			T	λ	S'	B	C_{ro}	C_T	K_j	CP_j	S_j	m
		2 yrs.	5 yrs.	10 yrs.	$\frac{(lb\text{-}sec)}{ft^2}$	cum (ft)								
AB	14×10^{-8}	46	80	114	3.7×10^5	65	.228	1.7	0.56	0.53	0.38	0.11	2.8	0.5
BC	"	"	"	"	"	145	.498	"	0.56	0.64	"	0.11	11.4	"
CD	"	"	"	"	"	300	.259	"	0.50	0.04	"	0.06	4.0	"
DE	"	"	"	"	"	506	.156	"	0.50	0.04	"	0.06	2.0	"

5. Calculation of Transport Capacity and Material Detached

(a). Transport Capacity

$$T_c = r \cdot R \cdot T \cdot \lambda^2 \cdot (S')^B \cdot C_{ro} \cdot C_T$$

(Haan and Barfield, 1978, Eq. 5.18)

T_c (lb/ft-width)

Segment	2 yr. Storm	5 yr. Storm	10 yr. Storm
AB	242	421	600
BC	5489	9546	13603
CD	431	750	1069
DE			

(b). Detached Soil

$$D_j = 0.0459 \cdot R \cdot K_j \cdot CP_j \cdot S_j \cdot (\lambda_j^{m+1} - \lambda_{j-1}^{m+1})/(72.6^m)$$

D_j (lb/ft-width)

AB	15	26	38
BC	151	263	375
CD	78	136	193

6. Routing of Sediment

Particles > 0.062 mm will be transported as Bed load - 65%

Particles < 0.062 mm will be transported as Suspended Load - 35%

The lesser of T_c and D_j is taken as the bedload sediment exiting each segment.

TABLE B5. ROUTING OF SEDIMENT

Segment	Detached Material (D_j) (lbs/ft-width) Total Load	Bed Load 1/	Suspended Load 1/	Transport Capacity (lbs/ft-width)	Material Transmitted from Segment (lbs/ft)
2 YEAR STORM					
AB	15	1/	1/	242	15
BC	151			5489	166
CD	73			431	244
5 YEAR STORM					
AB	26			421	26
BC	263			9546	289
CD	136			750	425
10 YEAR STORM					
AB	33			600	38
BC	375			13603	413
CD	193			1069	606

1/ Since $T_c > D_j$, it is not necessary to divide D_j into bed load and suspended load.

7. Sediment Load to Filter Area (See topo map Figure 7.)

TABLE B6. SEDIMENT LOAD TO FILTER AREA

Segment	Average Width (ft.)	Sediment Production (lb/ft.-width)	Total Sediment Production (lb)
2 YEAR STORM			
AB	190	15	2850
BC	180	166	29330
CD	165	244	40260
5 YEAR STORM			
AB	190	26	4940
BC	180	289	52020
CD	165	425	70125
10 YEAR STORM			
AB	190	38	7220
BC	180	413	74340
CD	165	606	99990

C. DEVELOPMENT OF POLLUTOGRAPH

1. Average Concentration

Return Period (yr.)	Sediment Yield (lbs.)	Runoff (in.)	Area (ft2)	(lb/ft^3)	Runoff (lb)	Concentration (lb/lb)
2	40,260	1.8	48477	62.4	453,745	0.089
5	70,125	2.7	"	"	680,617	0.103
10	99,990	3.2	"	"	806,657	0.124

2. Peak Concentration

(Ward, 1978)

Peak concentration can be predicted by:

$$C_p = 0.063577\ (Y_d/A)^{0.74}\ (q_p)^{-0.394}\ (t_{st})0.177$$

where:

C_p = peak inflow concentration $(^{mg}/l)$

Y_d = sediment delivery for storm (tons)

A = area (ac)

q_p = peak runoff rate (cfs)

t_{st} = storm duration (hrs.)

Return Period (yr.)	Y_d (Ton)	A (ac)	q_p (cfs)	t_{st} (hr.)	C_p (g/g)
2	20	1.1129	3.03	24	0.61
5	35	"	4.55	24	0.79
10	50	"	5.39	24	0.96

APPENDIX B

PLOTS OF SENSITIVITY ANALYSIS OF KENTUCKY GRASS FILTER MODEL

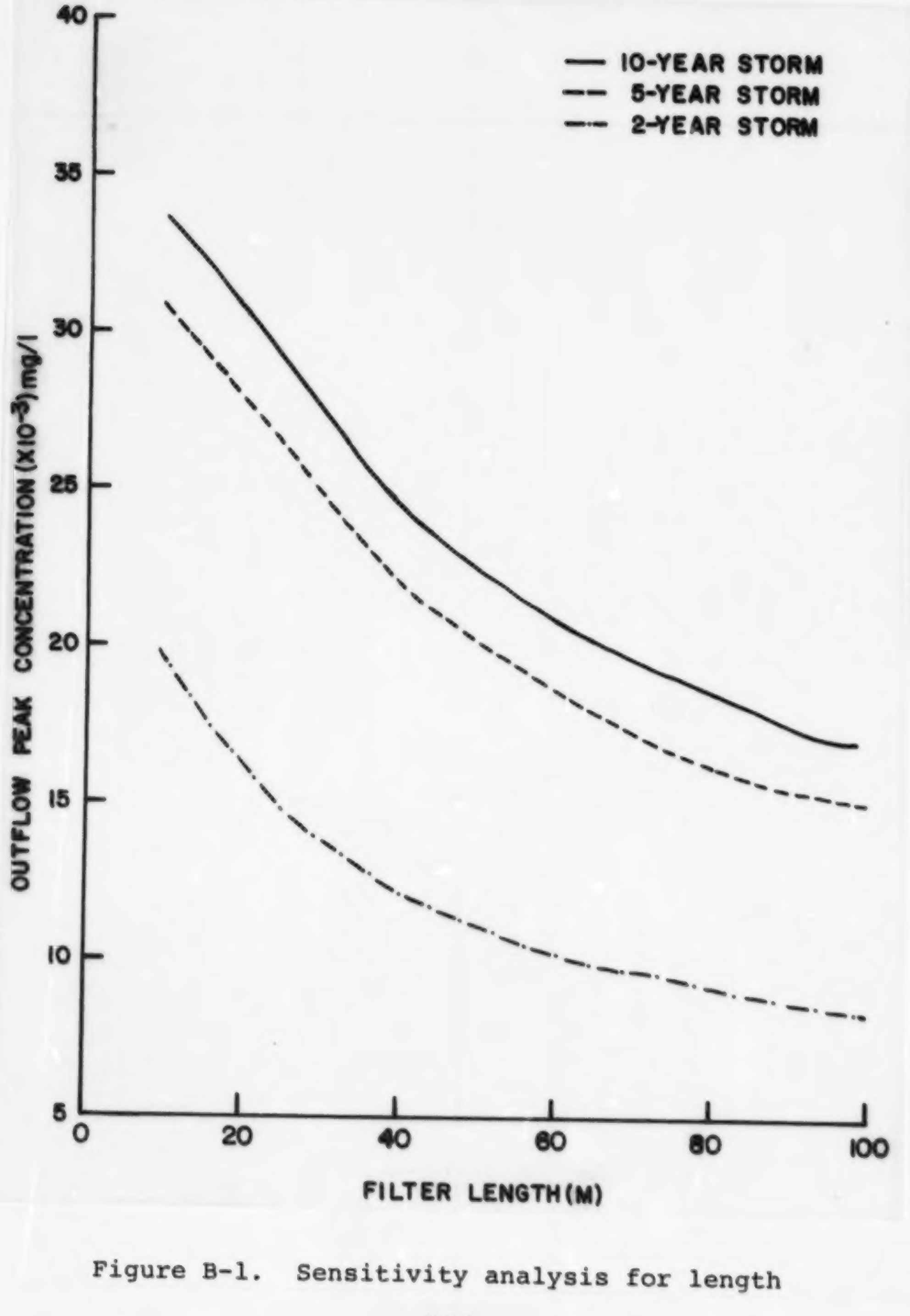

Figure B-1. Sensitivity analysis for length

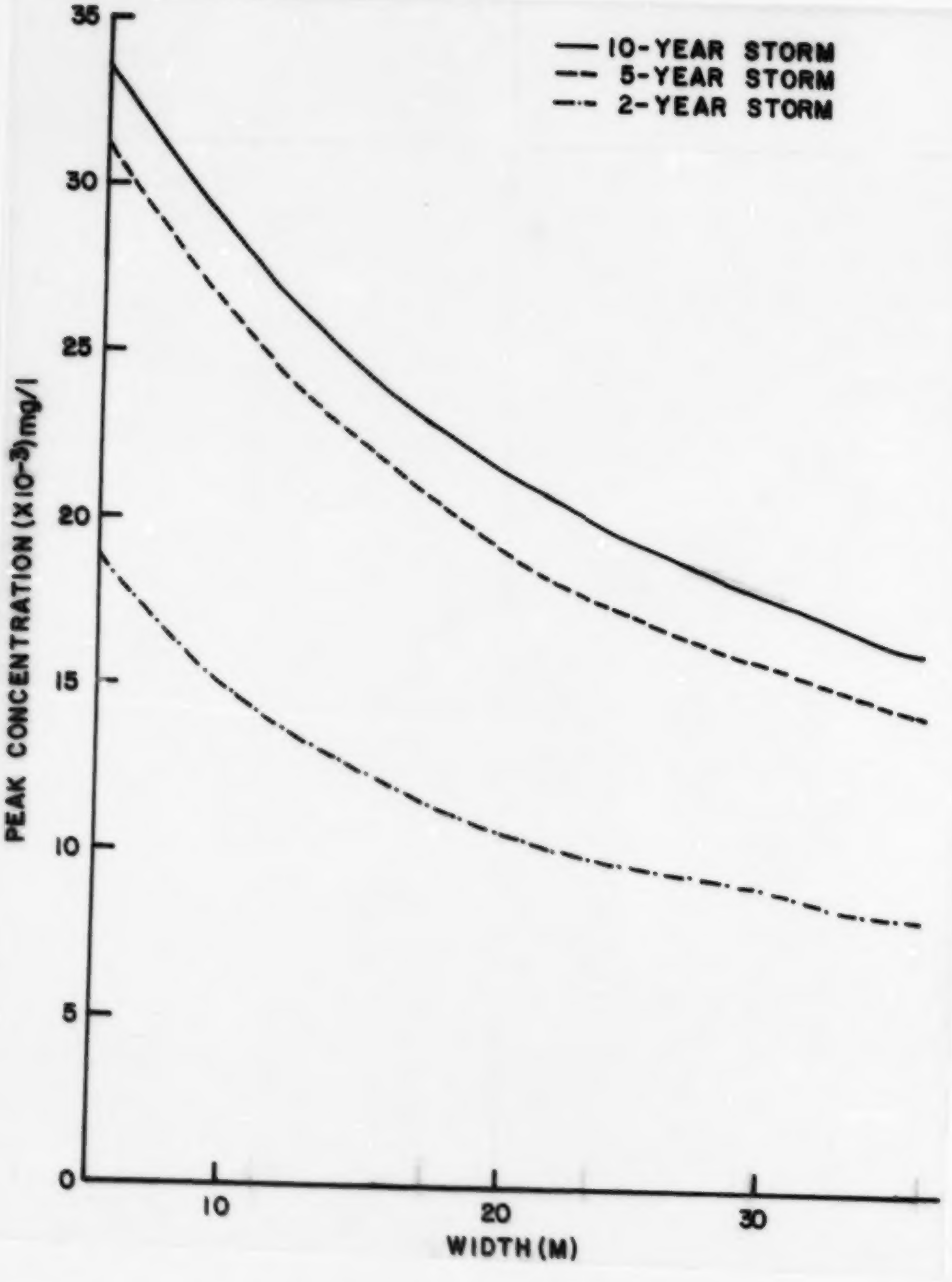

Figure B-2. Sensitivity analysis for width

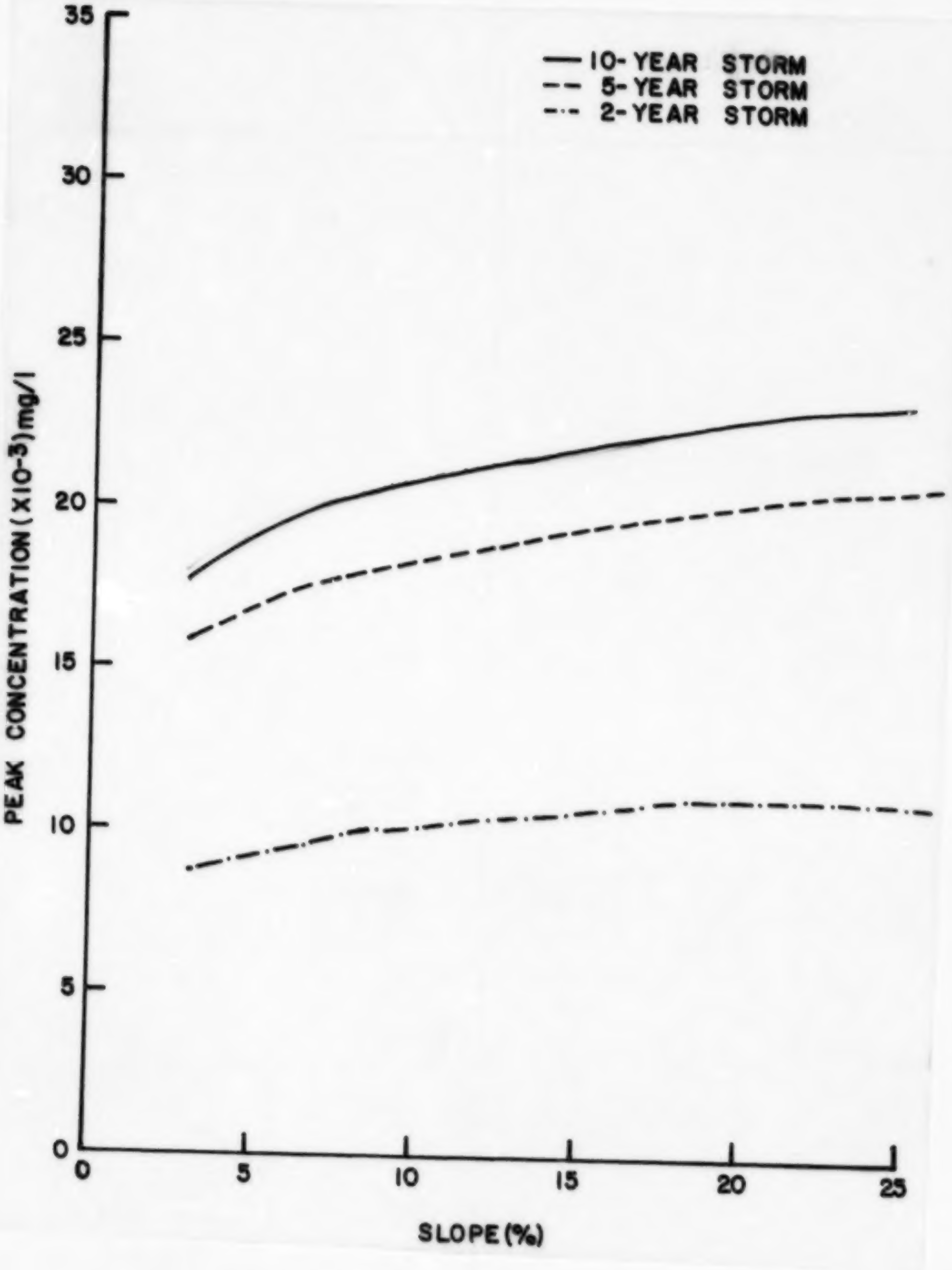

Figure B-3. Sensitivity analysis for slope

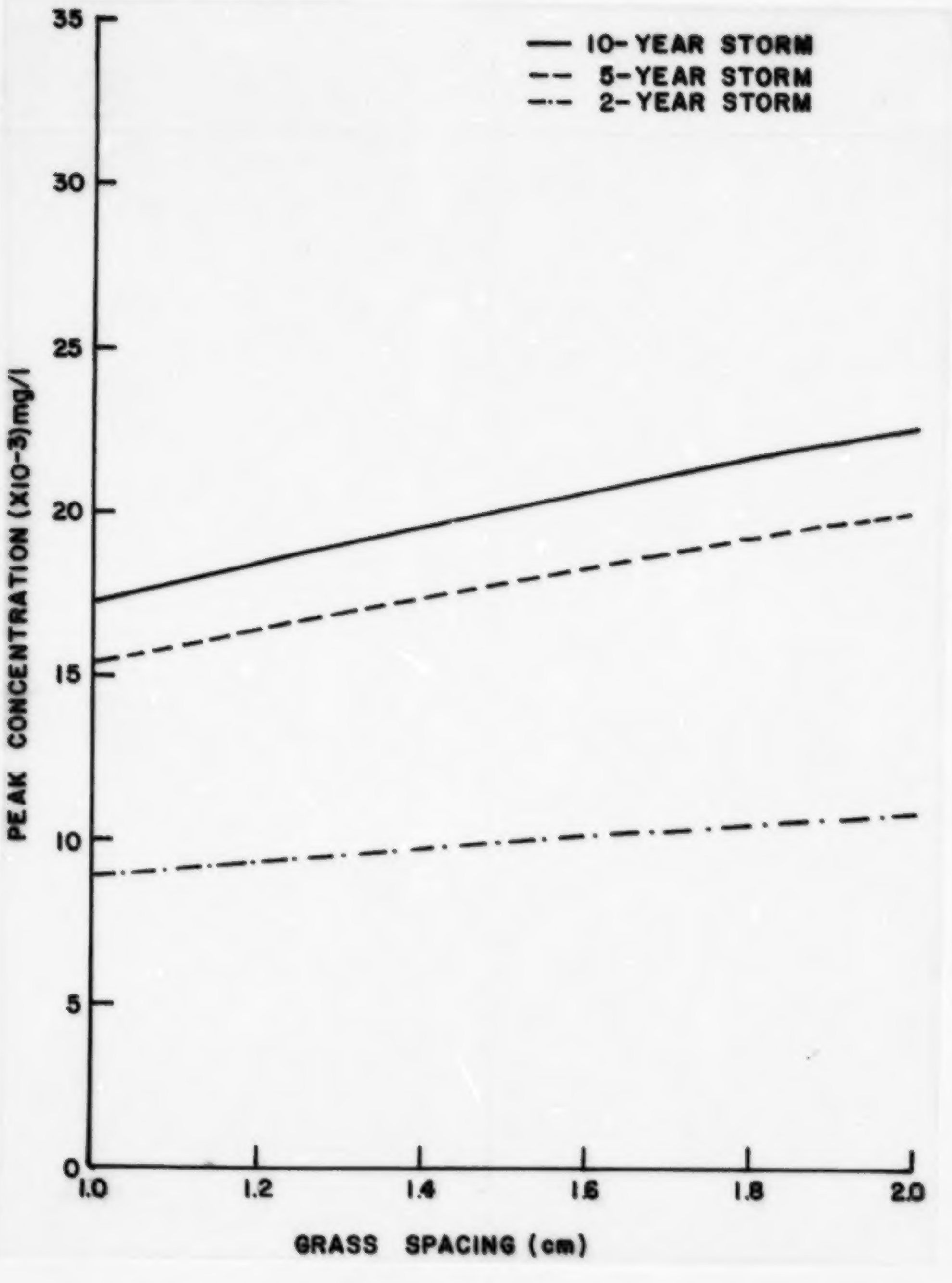

Figure B-4. Sensitivity analysis for spacing

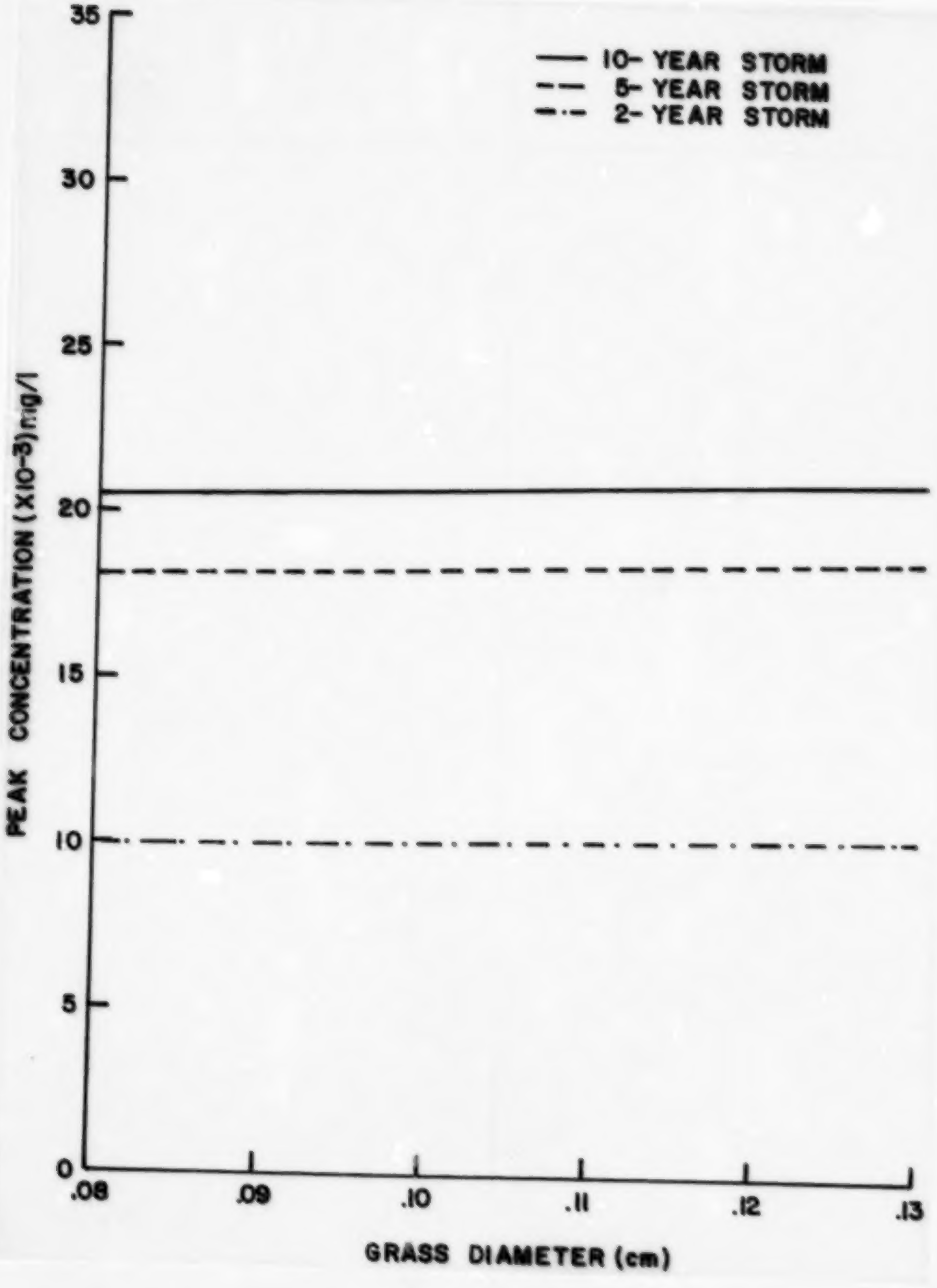

Figure B-5. Sensitivity analysis for diameter

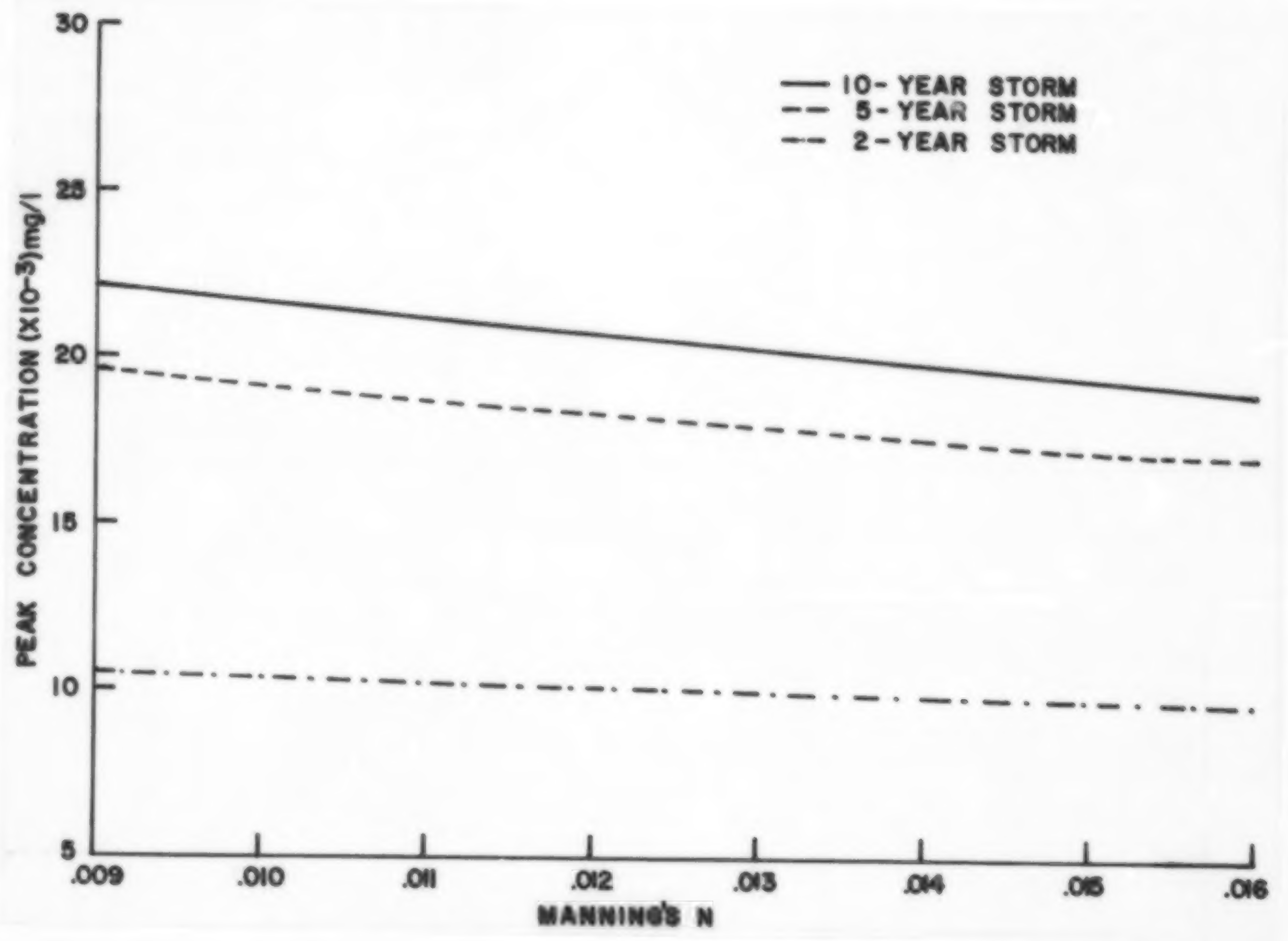

Figure B-6. Sensitivity analysis for Manning's N

APPENDIX C

ANALYTICAL PROCEDURES UTILIZED FOR PROJECT LABORATORY TESTING

All methods utilized during the course of the study for laboratory testing are contained in the following descriptions. Analyses performed on both water and soil are detailed in the information presented in this appendix.

WATER AND SEDIMENT TESTING METHODS

Pipette Analyses - Particle Size Distribution

Apparatus:

1 - 2000 ml graduated cylinder

1 - 1000 ml graduated cylinder

1 - 25 ml pipette

Filter papers (that trap .3 microns & larger)

Vacuum filtering stand

1 - thermometer

Drying oven (set at 105°)

Theory:

That pipette analysis of particle size distribution is based on Stoke's Law for fall velocity. This equation gives the equivalent spherical diameter for a given settling depth and time.

$$\frac{L}{t} = \frac{1\ g(d)^2(SGp-SGf)}{18\ \nu}$$

L = distance settled (cm)

t = time to settle (sec)

g = gravity (1000 cm/sec^2)

d = equivalent spherical diameter (cm)

S.G.p = specific gravity of particles (assume 2.65)

S.G.f = specific gravity of fluid used to suspend the particles (hour case water is used).

v = kinematic viscosity (temperature variable) (cm^2/sec)

Percent finer is calculated from

$$\frac{C_T}{C_i} \times 100$$

where:

C_T = concentration of 25 ml sample

C_i = initial concentration

Procedure:

Part I. Determination of sample concentration

1) A sample is thoroughly mixed by shaking the bottle (2-3 min.).

2) Immediately; a 25 ml sample is pipetted from the shaken sample.

3) The 25 ml are filtered through the filter paper. The pipette is rinsed with distilled water into the filter.

4) The filter paper (previously weighed) is dried at 105°C for 20-30 min. or until completely dry.

5) Concentration is calculated from:

$$\frac{\text{(Filter \& Sediment - Filter}}{25\text{ ml}} = \frac{\text{SED(g)}}{25\text{ ml}}$$

Part II. Pipette analysis

1) Weigh a full sample bottle.

2) A #270 sieve is placed in a funnel above a graduated cylinder.

3) The runoff sample is poured through the sieve. Distilled water is used to rinse the sample bottle.

4) Reweigh the sample bottle.

5) Wash the sieve residue into a previously weighed beaker. Put in drying oven until water is driven off. Weigh and record weight of beaker and sieve solids.

6) Wash the funnel with distilled water into the graduated cylinder. Fill the cylinder to a convenient readable level with distilled water.

7) Mix contents of cylinder by inverting continuously for one minute.

8) Set cylinder down (where it won't have to be moved) and start a stop watch.

9) Sample with a 25 ml pipette at depths and times that correspond to the particle size wanted.

10) Record the temperature of cylinder with distilled water as a control.

Example:

Time hr. min. sec	Depth	Size (dia.)
0:00:44	10 cm	.048 mm
4:26	10	.019
1:11:00	10	.0048
6:56	10	.002
7:10	5	.0014

11) Filter the 25 ml through a previously weighed filter paper, dry the filter paper, weight and record.

12) Determine 25 ml sample concentration (C_T) from:

$$C_T = \frac{\text{(Filter + Sed.) - Filter}}{\text{25 ml}}$$

13) Determine percent finer from (C_T/C_i) x 100 = % finer

SEDIMENT CONCENTRATION TESTING METHODS

Apparatus:

1 filter paper and filter pan per sample

1 beaker per sample

1 pipette

1 wash bottle

vacuum filter flask apparatus

drying oven

Procedure:

1) Filter paper is placed in filter pans and put in drying oven for approximately 15 minutes.

2) Bottles containing samples are weighed.

3) Beakers are numbered and weighed.

4) Pans and filters are removed from drying oven, numbered, and weighed.

5) Sample is allowed to settle until sediment is on the bottom of the bottle and the water above is relatively clear.

6) "Clear" water above sediment is removed with the pipette and poured through vacuum filter flask apparatus. Pipette is rinsed with distilled water into the filter flask.

7) Sediment remaining in sample bottle is poured into a beaker, and the bottle is rinsed with distilled water. Washings are added to the beaker of sediment.

8) Filters and beakers are placed in drying oven until all water has evaporated. When dry, they are weighed.

9) After the empty sample bottles have been allowed to dry out some, they are weighed.

10) Concentration is calculated from:

$$\frac{(\text{Filter \& Sediment}) - \text{Filter} + (\text{Beaker \& Sediment}) - \text{beaker}}{(\text{Bottle \& Sample}) - \text{bottle}} = \frac{\text{sed}\,(g)}{\text{sample}}\ (g)$$

SOIL TESTING METHODS

Standard EPA methods were utilized for all soil testing:

- pH (paste pH method)
- buffer pH (titration against a standard solution)
- phosphorus (extractable P)
- potassium (extractable K)

Source: EPA Field and Laboratory Methods Applicable to Overburdens and Minesoils, EPA-600/2-78-054, March, 1978.

GLOSSARY

acid soil: A soil with a pH below 7.1, but for practical purposes a soil with a pH of 6.6.

annual: Plant that completes its life-cycle in one year from seed.

cool-season: Grass species adapted to rapid growth during the cool-moist periods of the year.

flow hydrograph: A flow rate plotted opposite a time increment.

flow pollutograph: Concentration of pollutants versus time.

flow transport capacity: Mass of sediment which a flow will carry.

Manning's roughness coefficient: Values assigned to different materials to denote friction.

mg/l: Abbreviation for milligrams per liter which is a weight volume ratio commonly used in water quality analysis. It expresses the weight in milligrams of a substance occurring in one liter of liquid.

outslope: The slope formed on the outer edge of a spoil disposal area.

perennial: Plant that persists year after year without reseeding.

pH: The negative logarithm of the hydrogen-ion activity which denotes the degree of acidity or a basicity of a solution. Acidity increases with decreasing values below 7 and basicity increases with increasing values above 7.

point gauge: Device for manually measuring depth in a flume or weir.

reclamation: The procedures by which a disturbed area can be reworked to make it productive, useful, or aesthetically pleasing.

regrading: The movement of earth over a surface or depression to change the shape of the land surface.

sediment: Solid material settled from suspension in a liquid medium.

storm return period: Probability of a given rainfall to be equaled or exceeded during a given time period.

warm-season: A grass species adapted to rapid growth during the warmer parts of the year.